A HOMING TORPEDO
THE EFFECT OF THE TACTICAL SITUATION AND THE TORPEDO PARAMETERS ON THE TORPEDO EFFECTIVENESS.

Anders Mjelde

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

A HOMING TORPEDO.
THE EFFECT OF THE TACTICAL SITUATION AND THE TORPEDO PARAMETERS ON THE TORPEDO EFFECTIVENESS

by

Anders Mjelde

September 1977

Thesis Advisor: A. R. Washburn

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A HOMING TORPEDO. THE EFFECT OF THE TACTICAL SITUATION AND THE TORPEDO PARAMETERS ON THE TORPEDO EFFECTIVENESS		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; September 1977
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Anders Mjelde		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE September 1977
		13. NUMBER OF PAGES 168
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Naval Postgraduate School Monterey, California 93940		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Torpedo, homing, sonar, simulation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

When designing an active sonar homing torpedo, certain operational torpedo parameters such as speed, turn rate, etc. have to be decided upon. For a given homing torpedo, there must exist tactical guidelines of how to employ the torpedo, i.e. which firing position gives the best chance of a hit. This thesis attempts to gain some insight into the detection process during the torpedo run, as well as getting some indications of the relative importance of the different torpedo parameters and the tactical situations.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
(Page 1) S/N 0102-014-6601 |

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

A simulation model was used in order to generate the data base for analysis. The results stress the importance of a good firing position as well as show how it is possible to counter a bad firing position by a high speed torpedo. They also point to the importance of having only one detection as requirement for target acquisition.

A HOMING TORPEDO
THE EFFECT OF THE TACTICAL SITUATION AND THE TORPEDO PARAMETERS ON THE TORPEDO EFFECTIVENESS

by

Anders Mjelde
Lieutenant-Commander
Royal Norwegian Navy

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1977

ABSTRACT

When designing an active sonar homing torpedo, certain operational torpedo parameters such as speed, turn rate, etc. have to be decided upon. For a given homing torpedo, there must exist tactical guidelines of how to employ the torpedo, i.e. which firing position gives the best chance of a hit. This thesis attempts to gain some insight into the detection process during the torpedo run, as well as getting some indications of the relative importance of the different torpedo parameters and the tactical situations. A simulation model was used in order to generate the data base for analysis. The results stress the importance of a good firing position as well as show how it is possible to counter a bad firing position by a high speed torpedo. They also point to the importance of having only one detection as requirement for target acquisition.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENT.

The author wish to gratefully express his appriciation to his advisor, Professor Alan R. Washburn, for his advice, encouragement and guidance in the preparation of this thesis.

Lastly, but not least, my wife, Karen, and my kids must be acknowledged for their patience and endurance in waiting and hoping for the completion of this thesis.

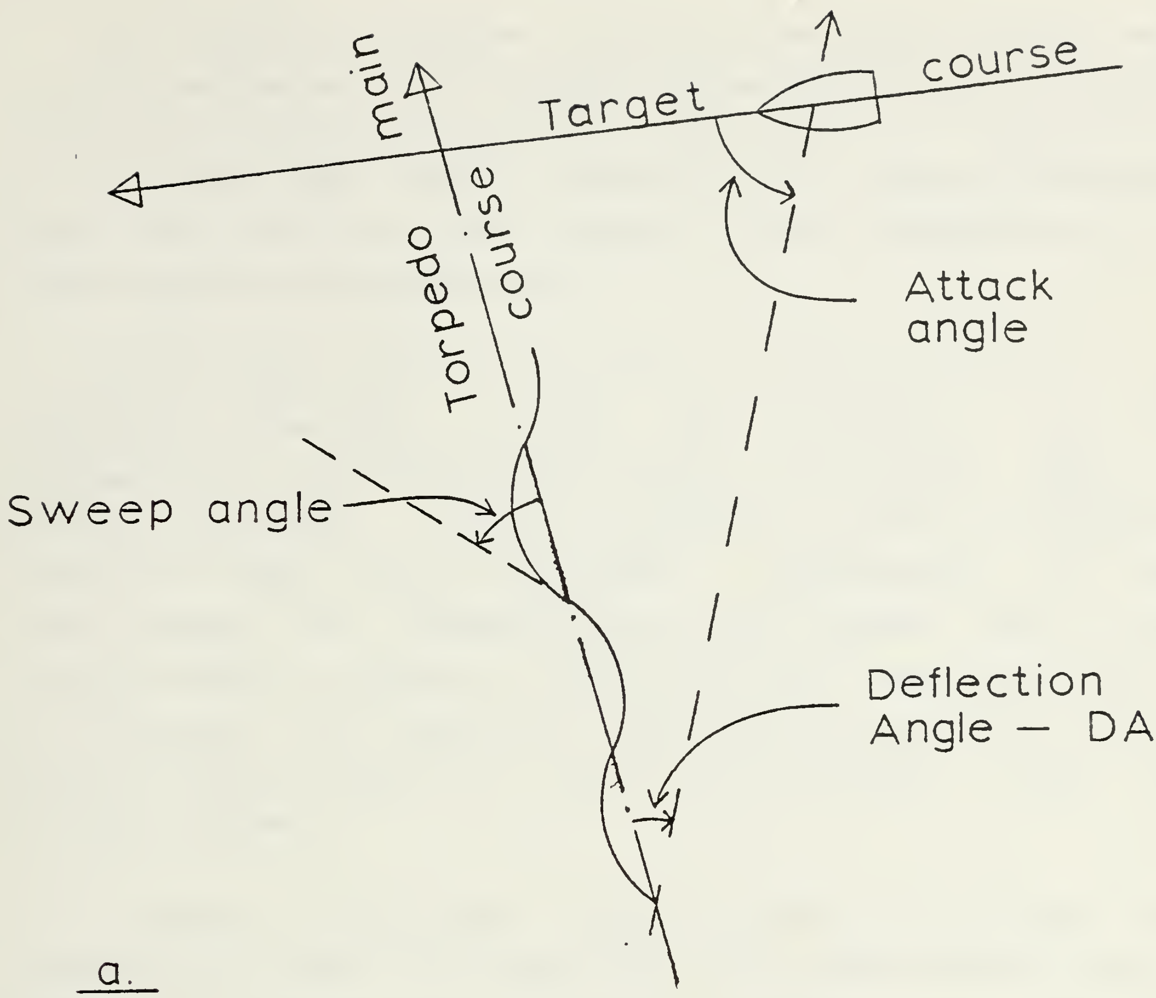
I. INTRODUCTION

The following analysis examines the performance of a homing torpedo against a surface ship. A homing torpedo is described as a torpedo which is searching/snaking on each side of its main course. It is searching for a target by transmitting with its sonar and listning for an echo. Ref. Fig. 1. Passive searching torpedoes and homing torpedoes going in circles are not investigated in this paper.

The torpedo's performance is a function of many variables. These variables are divided into two groups;

- technical variables; speed, max torpedo run, sweep angle, technical detection range, lobe characteristics and turn rate.
- tactical variables ; firing range, attack angle, target speed, type of target and tactical detection range (sonar conditions).

No attempt is made to analyze the first group of variables; instead, technical variables used are those of present technology. We are assuming a 'standard homing torpedo' based upon homing torpedoes in operational use today [8]. This 'standard torpedo' assumes conventional warhead and active sonar transmission for detection., and is unguided.



a.

b.

Figure 1 - A HOMING TORPEDO

The technical variables (torpedo parameters) are in many ways interrelated. For example, the maximum detection range will determine the transmission rate, since the transmitted energy must have time to traverse out to maximum detection range and return as an echo before the next transmission, at least during the search phase.

At the same time the torpedo is transmitting, it is searching (changing course) for a target. In each transmission, the transmitted energy is focused within a narrow beam(lobe). During reception, the echo is confined within the same narrow beam(lobe). Concurrently, in the time between two transmissions the turning rate of the torpedo must be limited to ensure that the receiving lobe is not outside the direction from where an echo may return. Thus turn rate should be a function of detection range and the lobe pattern.

In order to maintain torpedo speed, the number of degrees of sweep on each side of the main course must be small. If the sweepangle is small, however, the width of the possible detection lane will be small as well, and consequently the detection probability might be reduced during transit. Also, a high torpedo speed creates a great change in torpedo position between each transmission. In this way the torpedo may scan outside a target in the sweep lane. In other words, the coverage density of the lobe may be low as a result of the high movement rate.

As we recognize the relationship between torpedo parameters, tactical variables and torpedo performance, we know that frequently within the naval establishment decisions have to be made with regard to torpedo parameters and tactical doctrines. In localizing and defining these relationships this analysis may be a tool in this

decisionprocess.

The measure of effectiveness by which different alternatives will be judged will be detection probability, by which is meant the probability that the torpedo's active sonar detects and begins to track the target. This probability will be measured by a digital computer simulation, construction of which was a major part of the author's effcrt in writing this thesis.

II. NATURE OF THE PROBLEM

A. DEFINITIONS

Lobe width is the number of degrees from the centerheading of the torpedo, until the first minimum in transmission intensity is reached. See Fig. 4.

Detection range is the range to the target when detection first occurs.

Technical detection range is the max detection range which is technically and reasonably possible considering power transmitted and lobewidth. It is the basis for determining the transmission rate.

Aspect is the angle measured from the positive direction of the longitudinal axis of the target to a line joining the centers of gravity of the target and the torpedo.

Attack angle is the aspect at the start of the torpedo run.

Sweep angle is the maximum number of degrees the torpedo will turn off the main course during search.

All dimensions are in meter, second, meter per second, degree, degree per second. Speed of the target and the torpedo are, however, always given in knots.

It is assumed that all firings are successful, and the torpedo will not deviate from its ordered/calculated course and speed.

All firings are made with a deflection angle; i.e. the torpedo is given a course to a predicted hitting point with the target.

B. ASSUMPTIONS

Not only in order to keep the problem tractable, but also because of modern torpedo development, only surface targets are considered. Previously within NATO, torpedo developments seemed to start as a development of an anti-submarine torpedo with later modifications in order to make the torpedo dual purpose. However, today there are some indications that the anti-surface ship requirement is coming into the development early in the planning process [7;8;9]. The entire problem is then kept in two dimensions. The vertical axis is not significant as we assume isovelocity condition, and we assume for simplicity that we have negligible surface effect.
Also, if the intensity of the echo is above detection threshold level, the target is detected with probability one. Probability of false contact is assumed to be zero.

The main purpose of a homing torpedo is to counter uncertainty in target data at firing and target maneuvering after firing.

For simplicity the following assumptions are made:

- the target remains on a steady course after firing.
- estimated target data is used in solving the deflection angle problem

- deflection angle(DA) is given by;

$$DA = ARCSIN((TAM \times SIN(ASP))/TO) \qquad (2.1)$$

TAM = target estimated speed

ASP = estimated aspect
= (target estimated course) - (bearing to torpedo)

TO = torpedo speed.

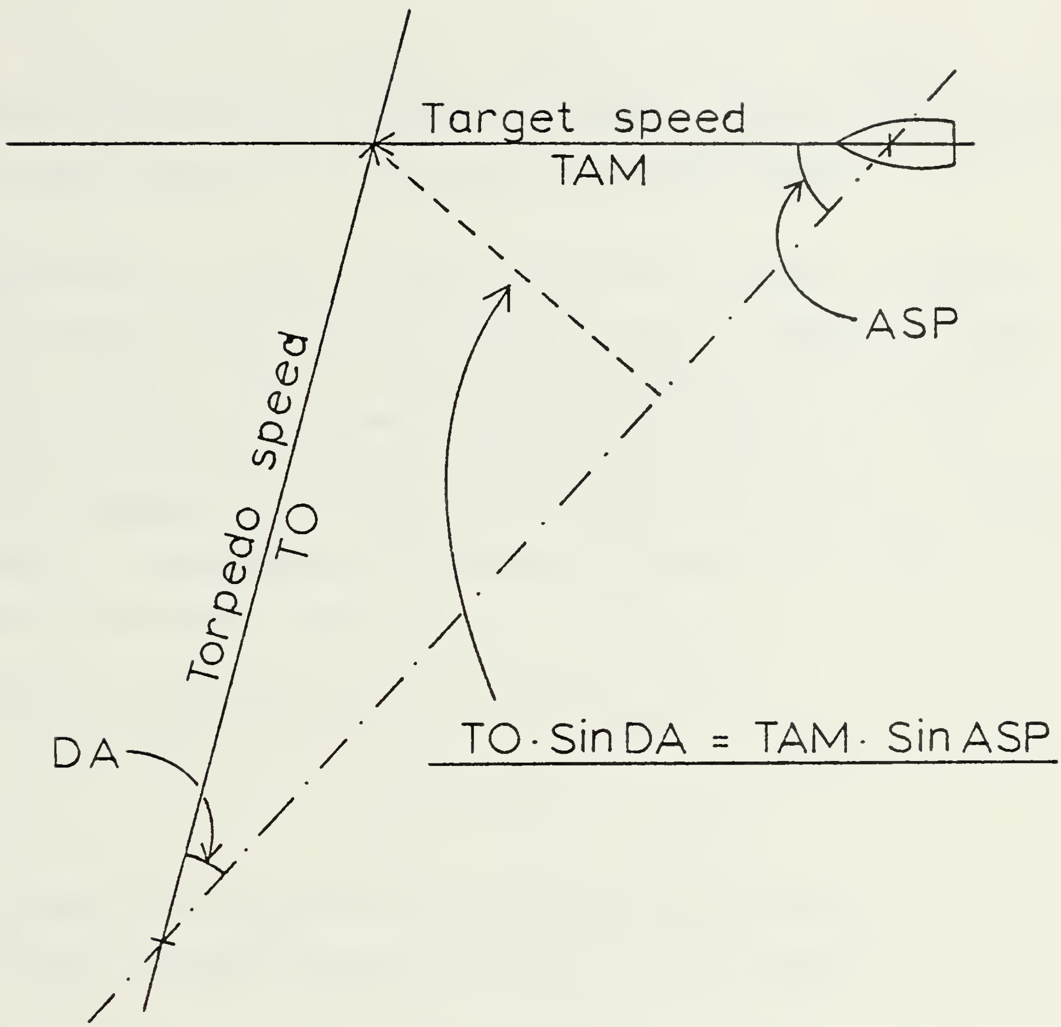
See Fig. 2.

The difference between the target data and the target estimated data are defined as errors in the target data. These errors are assumed to be random variates and are given as;

- target range error is uniformly distributed between - 15 % and + 15 % of actual target range
- target course error is uniformly distributed between - 15 and + 15 degrees
- target speed error is normally distributed with mean 0 and standard deviation 3 knots.

These errors are assumed to cover errors in the fire control solution at the time of firing as well as non-radical maneuvering of the target during the torpedo run.

As shown in Eq. 2.1, estimated range does not enter into the calculation. Estimated range would only be used for some more complicated tactical situations as angled torpedo firing off the firing course of the firing unit. These situations are not covered in this study.



ASP — Estimated Attack angle
DA — Deflection angle

Figure 2 - TORPEDO TRIANGLE

III. PROBLEM SOLVING APPROACH

At firing, the initial course of the torpedo is uniformly distributed between minimum course and maximum course (main course +/- a fraction of sweep angle).

Immediately after firing, the torpedo starts 'snaking'. During snaking, the torpedo is continously changing course left or right out to the given sweepangle, then back past main course and out to sweepangle on the other side and so on. The torpedo is turning with the given turnrate. During the whole process, the torpedo is also transmitting and listening. Transmission interval(TTIME) is given by technical detection range as;

$$TTIME = 2 \times TEDEC/1500 \quad \text{seconds} \tag{3.1}$$

where

TEDEC = technical detection range in meters.
1500 = speed of sound in salt water, m/sec.

The torpedo run is conducted in steps. Every 0.5 seconds interval, all positions and courses are updated.

At each transmission; the relative bearing to target, and the target aspect are calculated in order to establish the intensity of the echo.
When a detection occurs, the following data is stored;

- detection range to the center of the target.

- detection range to the nearest part of the target.
- detection bearing (relative) to the center of the target.
- detection bearing(relative) to the nearest part of the target.
- target aspect.

In addition to the detection probability, the range at which the detection first occurs is also of interest. Therefore, we store these data at the first detection.

However, successive detections are also important. As part of the criterion for the decision of when to go from search-phase to attack-phase, the number of successive detections (with no non-detection between) may be employed. In real life there is always a positive probability of false detection. Even if we are not addressing the problem of false contact as such, we can cover the possibility by requiring the torpedo to have at least two successive detections before going into attack-phase. Accordingly, we store also the previously listed data at the second successive detection(two immediately following detections), at the third and so on, up to and including 5 successive detections. This listing of detections will give an indication of the decrease in detection probability if a large number of successive detections before going into attack-phase is required in order to decrease the probability of false contacts.

IV. MODEL

A. SEARCH

For simulating the torpedo search, a Fortran IV simulation program was developed.

The program was divided into;

- Main program, including generation of statistics and print out of summary after all the runs were completed.
- Subroutine PARMET for setting tactical situation and torpedo parameters.
- Subroutine FIRING which calculates estimated target data, and the deflection angle.
- Subroutine POSIS which calculates the torpedo course, and torpedo and target positions at each time step.
- Subroutine DETECT which checks if the target is detected and if so, store detection data.

See Fig. 3.

See Appendix A and Appendix B.

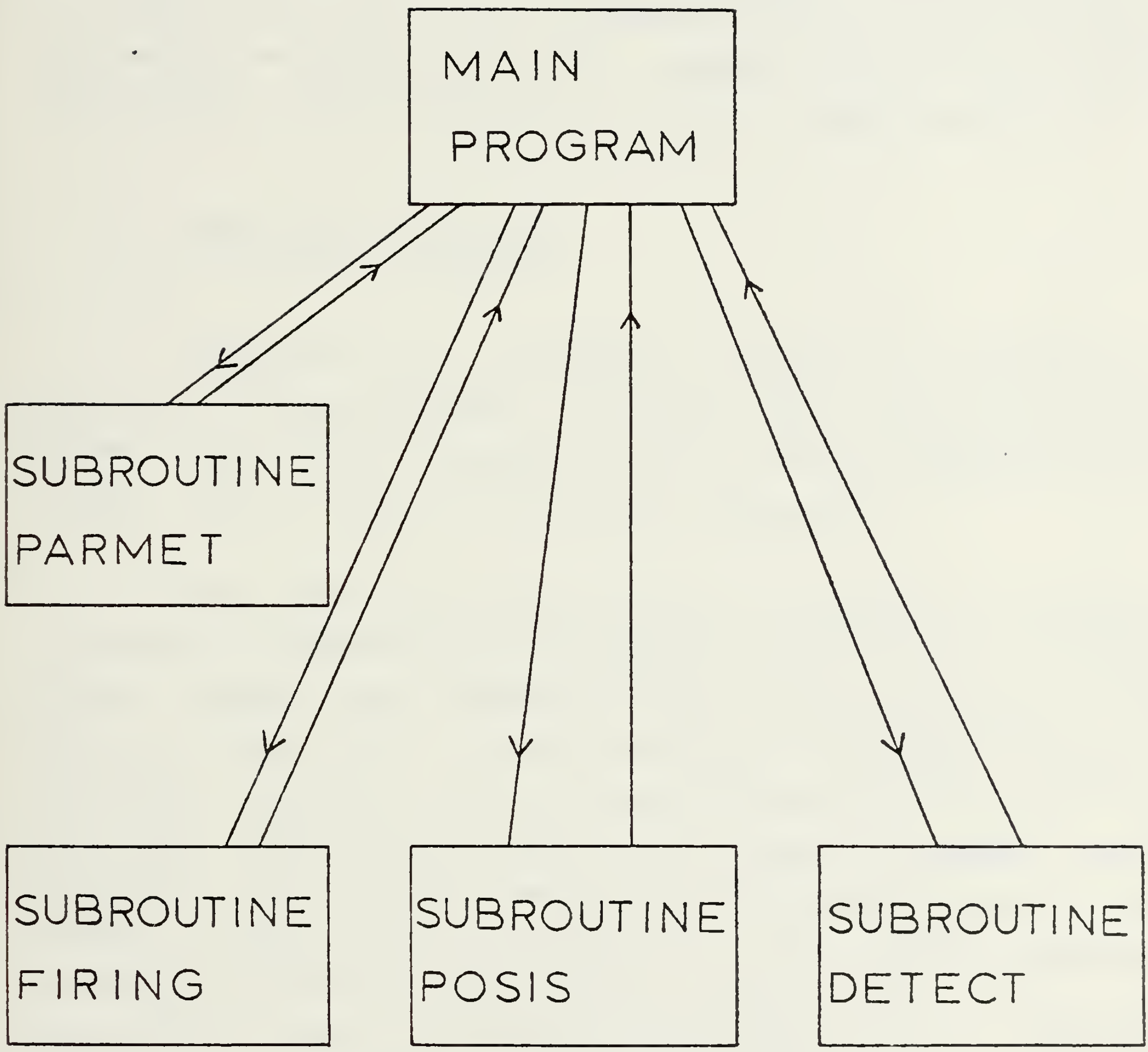


Figure 3 - STRUCTURE OF COMPUTER PROGRAM

B. DETECTION MODEL

A contact occurs when the acoustic energy-pulse generated at the transducer and reflected from the target as an echo, is at or above threshold level. In the following discussion we assume that the contact meets the tactical requirement, and accordingly we use the term detection.

1. Detection Threshold

Deciding if a detection occurs is a function of detection threshold(signal to noise ratio), the range to the target, the target strength and the relative bearing to the target, given a level of radiated intensity.

The detection threshold for a torpedo is a function of design and technological sophistication of the torpedo. Without making any assumption about these variables in the model, we start with a given technical detection range, a 'standard' target, and calculate intensity of echo at that range for target aspect equal to 90 degrees(maximum target strength) and relative bearing to the target equal tc zero degrees. This echo intensity is then the detection threshold for every transmission during a run. If any echo intensity is above the detection threshold, it is detected; if below the detection threshold, it is not detected.

2. Echo Intensity

In calculating echo intensity we must separately investigate the important factors, which are transducer

gain, lobe characteristic, transmission loss and target strength. The model used is described below.

a. Lobe Characteristics

The transducer has a main lobe and many sidelobes as a function of the transducer's gain and relative bearing. Urick [6;51-57] discusses some of the different types of beam pattern (lobes), and the following mathematical model was developed and found to give an acceptable pattern;

$$G(\theta) = G_0 \left| \frac{\mathrm{SIN}(x\,\pi)}{x\,\pi} \right| \mathrm{COS}(\theta/2) \tag{4.1}$$

where

$$x = \theta/\theta_0 \tag{4.2}$$

and

G_0 = maximum gain

θ = relative bearing

θ_0 = lobe width.

This model will produce the gain-pattern as shown in fig. 4.

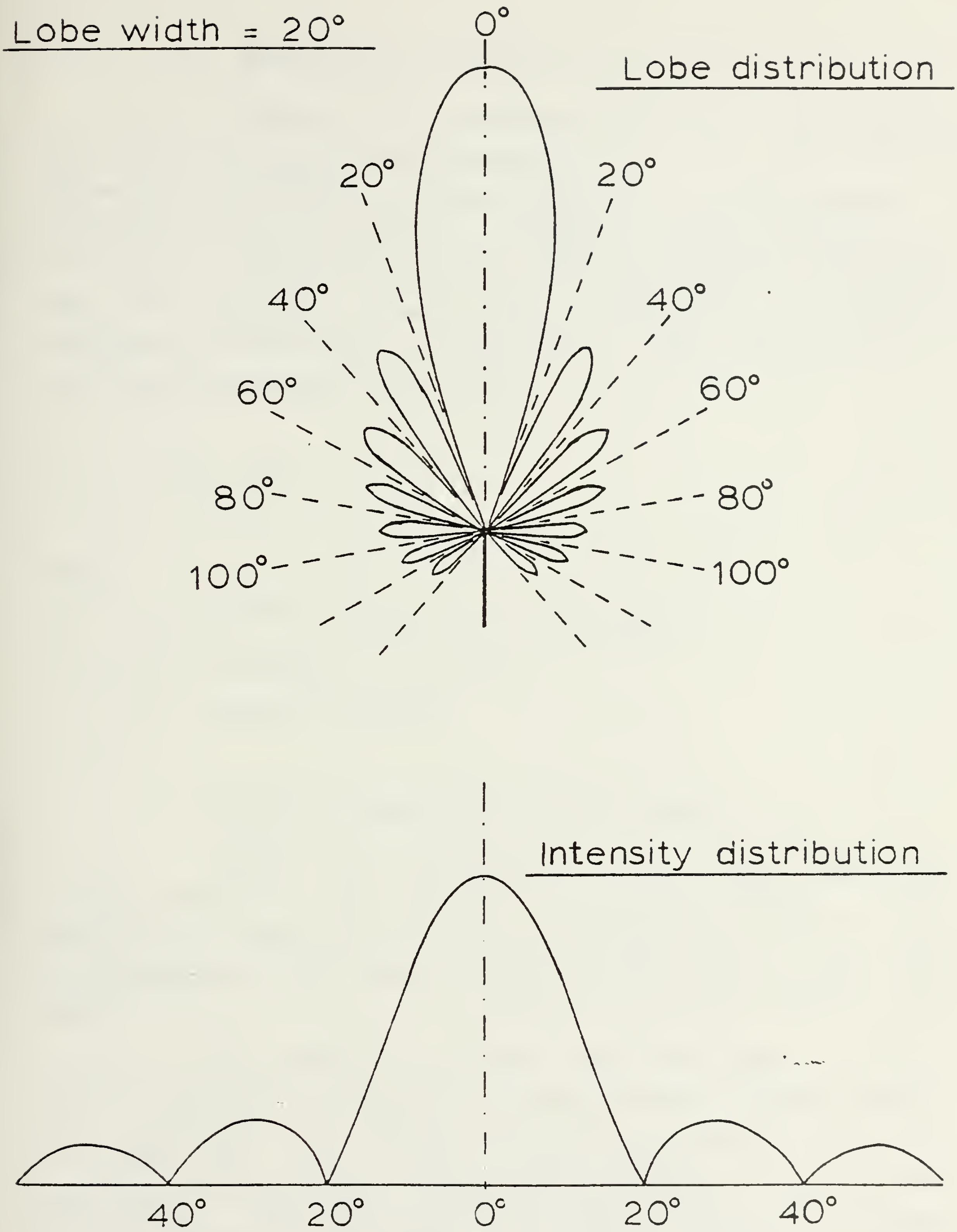


Figure 4 - DISTRIBUTION OF LOBES AND INTENSITY

b. Reduction in Intensity due to Range

Primarly, the reduction is due to two effects; spherical spreading and absorption.
Spherical spreading is a known function, but absorption is dependent upon transmission frequences, water, salinity etc. In order to simplify the model and since spherical spreading has the greatest effect, only the spherical spreading for reduction in intensity is considered. This reduction in a one way propagation is given by;

$$I = I_0/R^2 \tag{4.3}$$

where

I_0 = radiated intensity at one meter

I = intensity at range R.

R = range in meters.

c. Target Strength and Target Aspect

When the transmitted energy pulse hits the target, some of the energy is reflected back to the transducer. The echo intensity is a function of the shape and dimension of the target, type of reflective material and aspect.

It should be noted that the notion of target strength represents the ratio between target cross section and the surface of a sphere of radius 1 meter, or if in dB, 10 times the log of this ratio; base 10. In most references, the target strength or the target cross section is given abeam of the target, see [5;97],[6;274], without presenting the cross section as a function of the aspect. Urick [6;282,283] gives , however, as figures, an indication

of how the target strength(in dB) varies with the aspect. Cox[3;60] states that it will vary between 10 and 25 dB. All measurements in dB in the two references are relative to 1 yard as unit for range. Urick[6;283-286] indicates that his reference (as given in the figures) will not change in any considerable degree with changes in frequencies (20-60 KHz) or for different targets (submarines/surface ships).

Assuming a torpedo with transmitting frequency between 50 and 60 KHz, we get a wavelength varying between 2.5 and 3.0 cm (0.025 - 0.03 meters). As any reflection from a target is mostly determined by target form, size, aspect and wavelength, we may use a model from radar theory in our next step. The justification for this use is that in radar theory we are working in the same area of wavelength and target dimension as an active sonar for a homing torpedo.

Crispin and Siegel [4;86] give for target cross section a model for an ellipsoid where the incident angle (target aspect) is a variable. The relationship is as follows;

$$\sigma = \frac{\pi \cdot a^2 \cdot b^2 \cdot c^2}{(a^2 \cdot \mathrm{SIN}^2 \theta \cdot \mathrm{COS}^2 \phi + b^2 \cdot \mathrm{SIN}^2 \theta \cdot \mathrm{SIN}^2 \phi + c^2 \cdot \mathrm{COS}^2 \theta)^2} \qquad (4.4)$$

a, b, c being half axes of the ellipsoid.
Ref. Fig. 5.

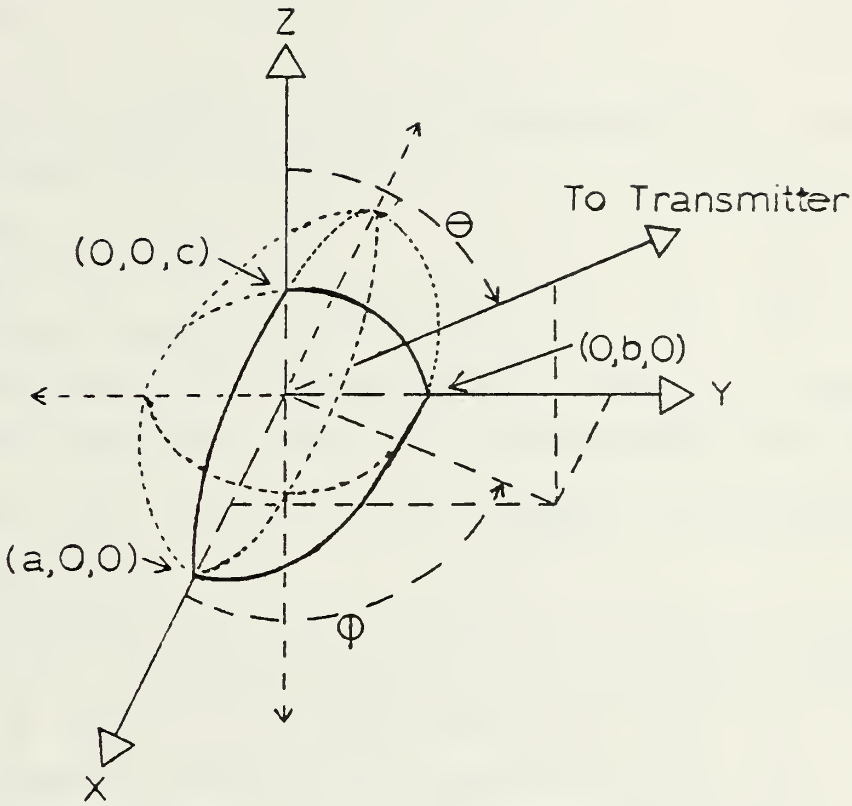


Figure 5 - MODEL OF TARGET AND TARGET ASPECT

As we assume that the transmitting pulse is always in the horizontal plane, θ is 90 degrees, which gives us;

$$\sigma = \frac{\pi \cdot a^2 \cdot b^2 \cdot c^2}{(a^2 \cdot \cos^2 \varphi + b^2 \cdot \sin^2 \varphi)^2} \qquad (4.5)$$

φ = aspect.

Urick [6;275] gives for target section a model for abeam or ahead cases, which is;

$$t = \sigma/(4\pi) = (b \cdot c/2 \cdot a)^2,$$

identical with Eq. 4.5. Note that Eq. 4.5 is an expression for the target cross section.
Haslett [5;139] gives for the target cross section a model for both ahead and abeam cases. His model equals Eq. 4.5 times a factor $\underline{R}^2$, where $\underline{R}$ is acoustic reflectivity coefficient (per cent) = 94.
The advantage of using Eq. 4.5 is that it gives the target cross area as a continous function of the target aspect. For our model we will only use the lower part of the ellipsoid to simulate the ship hull below the water line.

Combining Eq. 4.5 and acoustic reflectivity coefficient we get the following model for the target cross section;

$$\sigma = \frac{\pi \cdot a^2 \cdot b^2 \cdot c^2 \cdot \underline{R}^2}{(a^2 \cdot \cos^2 \varphi + b^2 \cdot \sin^2 \varphi)^2} \qquad (4.6)$$

With reference to Urick's figures [6;283] where the pattern of the target strength is given as a function of

aspect in Fig. 9.13, and reproduced in this analysis as Fig. 6.a, we still have not obtained a model which gives the same type of pattern. By applying the following scaling factor to Eq. 4.6 we have approximated his information:

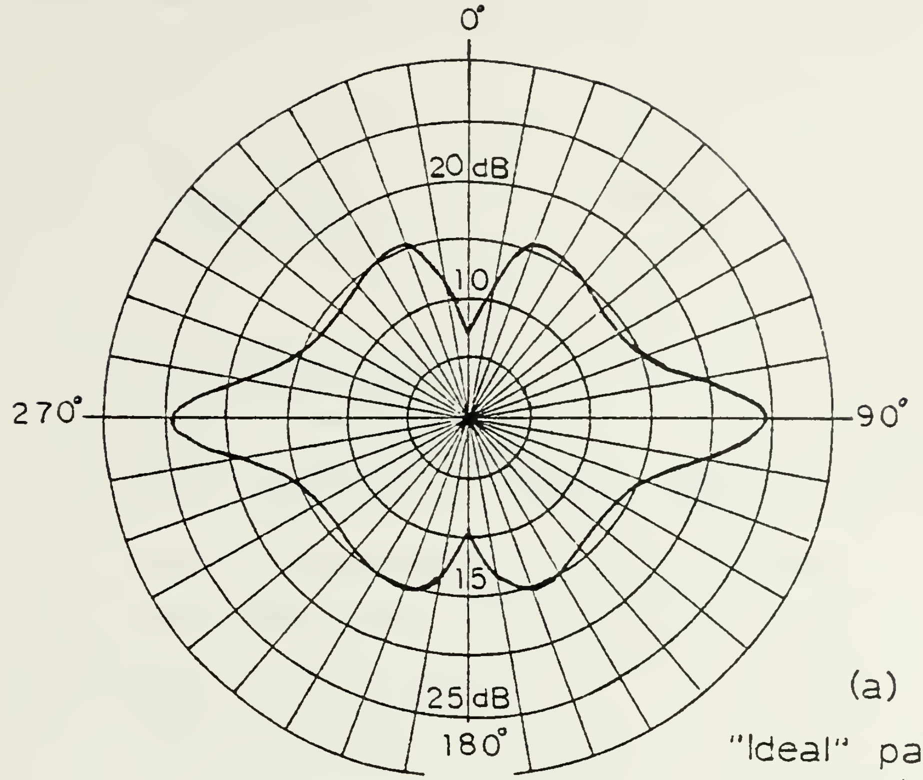
$$U = (0.251635 \cdot \varphi^2 - 0.18555 \cdot \varphi + 0.0365 \cdot \mathrm{SIN}(3 \cdot (\varphi + 0.17453)) + 0.015 \cdot \varphi^2 \cdot \mathrm{SIN}(9 \cdot \varphi/2))^{-1} \qquad (4.7)$$

We then have as the target cross section in our model the following expression;

$$\underline{\sigma} = \sigma \times U \qquad (4.8)$$

where σ and U are as previously shown.

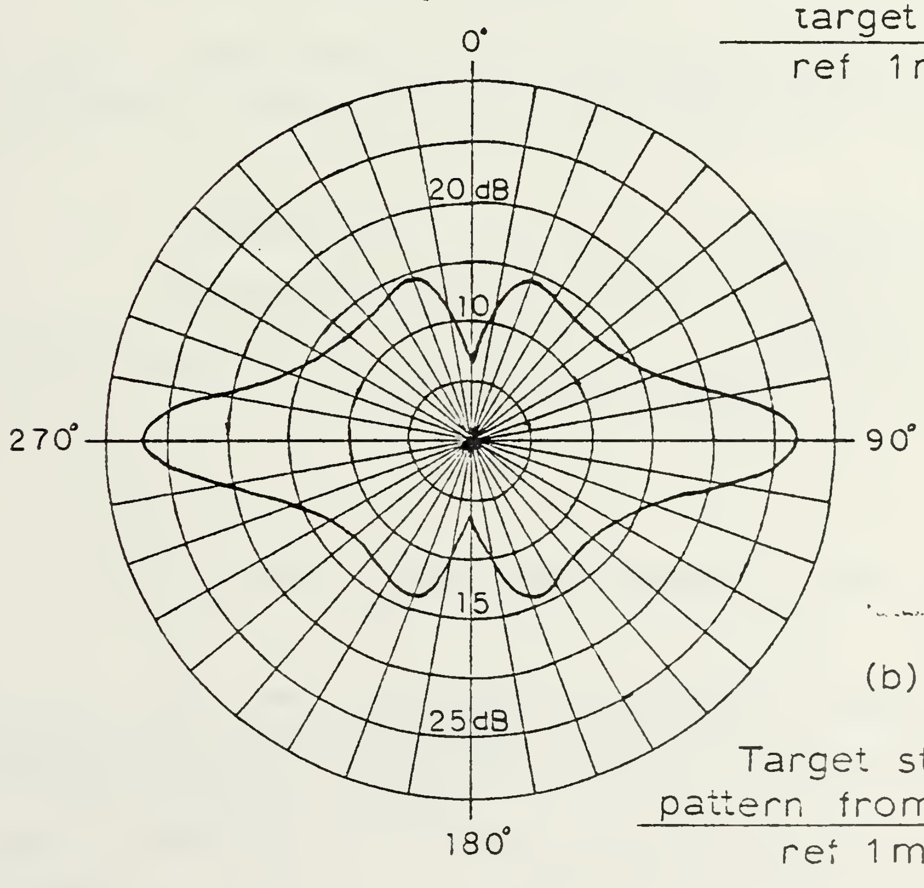
Fig. 6.a and Fig 6.b shows an 'ideal' pattern and a model pattern. The figures given by Urick are for 1 yard as reference distance, but have been converted to 1 meter reference distance in Fig. 6. To go from dB(yard) to dB(meter), we subtract 0.78 dB. The dB as given in this analysis are all with 1 meter as reference distance.



(a)

"Ideal" pattern for target strength

ref 1m



(b)

Target strength pattern from model

ref 1m

Figure 6 - TARGET STRENGTH

The active sonar equation is;

$$P = \frac{P_0 \cdot G_t \cdot \underline{\sigma} \cdot G_r \cdot \lambda^2}{(4 \cdot \pi)^3 \cdot R^4} \quad \text{Watts} \tag{4.9}$$

P = power received

P_0 = power transmitted

G_t = gain transmitting, ref Eq. (4.1)

$\underline{\sigma}$ = target cross section, ref Eq. (4.8)

G_r = gain receiving, ref Eq. (4.1)

λ = wavelength in meters.

R = range to target in meters.

This may be rewritten into an expression of power received as a function of the variables of the different terms;

$$P = K \frac{\left| \frac{\sin(X_t \cdot \pi)}{X_t \cdot \pi} \right| \cdot a^2 \cdot b^2 \cdot c^2 \cdot \underline{R}^2 \left| \frac{\sin(X_r \cdot \pi)}{X_r \cdot \pi} \right|}{R^4 \cdot (a^2 \cdot \cos^2 \phi + b^2 \cdot \sin^2 \phi)^2} \tag{4.10}$$

K = the product of all the constants in the terms.

For more detailed discussion about gain, transmission loss and reflection (target cross section), see [1;110-111] and [6;29,94,263].

We can now calculate the minimum power level for detection by setting:

R_t = technical detection range

X_t = 0 degree

X_r = 0 degree

Φ = 90 degrees

and we get

$$P_{min} = K \frac{a^2 \cdot b^2 \cdot c^2 \cdot R^2 \cdot U}{R_t^4 \cdot (b^2)^2} \qquad (4.11)$$

and by substituting for U

$$P_{min} = K \frac{a^2 \cdot b^2 \cdot c^2 \cdot R^2 \cdot 3.08657}{R_t^4 \cdot (b^2)^2} \qquad (4.12)$$

a, b and c are the dimension of the target used in the model.

We assume a 'standard' target, length 100 meters, beam 15 meters and draught 4 meters, i.e.

a = 100

b = 15

c = 4.

There will be a detection if $P/p_{min} > 1$. Note that P/P_{min} does not depend on K, into which radiated power and transducer gains have been included. The technical detection range R_t is an operationally meaningful surrogate

for these parameters. The ratio P/P_{min} will be called the "intensity fraction".

3. Detection Rule

Any intensity-fraction calculated during a transmission which is greater than 1 is a detection. However, to improve the model at close ranges, the following modification has been made for gain variation due to relative bearing.

At close ranges, the relative bearing to target can alter considerably from bow to stern. Therefore, the intensity in the pulse will differ along the target. To average this intensity both for the radiated pulse and for the echo, the model calculates relative bearing to the target bow, center and stern, calculates the corresponding gain factor for each bearing, and finds the arithmetic mean of these gain factors. These two average gainfactors (transmitting and receiving) are then used in the calculation of echo intensity.

The model does not recognize a detection unless the tactical situation makes it possible to maintain contact with the target for some time. To be precise, the following conditions must be present;

- torpedo turn rate higher than bearing rate
- closing speed must be positive.
- target must have 2 knots doppler.

V. PRESENTATION OF DATA

A. STOCHASTIC ELEMENTS

In the previous description of the model, the following input values are stochastic;

- error in target speed
- error in target course
- error in target range
- initial torpedo course(not main course).

The primary stochastic effects on the torpedo performance are identified as errors in target speed and course, since these two variables are the only stochastic ones used in computing the torpedo main course. The first problem to be solved was then how to design the run series in order to reduce variance in result at the same time as keeping the result unbiased.

It was found that instead of using a complete randomized design (random variates); we could deterministically section the probability range 0.0 - 1.0 for the two important random variables, using the inverse probability transformation to get variates, and then run the number of runs required to cover all combinations of variates.

Some preliminary simulation runs were done in three

versions; complete randomized and independent; with antithetic reduction technique (sectioning); and the previously described procedure. The number of runs needed in order to keep the variance low for the result was considerably higher for the first two versions. Accordingly, we selected the previously described procedure. It was found that a series of 150 runs was sufficient in order to give a reasonable accuracy in detection probability and at the same time keeping the total CPU time for a series of runs acceptably low. The 150 run series was established by dividing the range of probability of target speed errors into 15 equally spaced sections; and the range of probability of target course errors into 10 equally spaced sections. Each section boundary point was by inverse probability transformation converted into a variate. Bearing in mind that speed errors are normally distributed and course errors are uniformly distributed, all combinations of target data error are plotted in Fig. 7.

Figure 7 - DISTRIBUTION OF ERROR IN TARGET DATA

B. TYPE OF PRINTOUT OF DATA AND RESULT

Each series of 150 runs produces a printout as shown. The heading cf the printout gives the tactical situation and the torpedo parameters in the given run series. Also , the printout gives the sweep lane, which is the width of the lane where the torpedo has swept through by its sonar lobe. The coverage ratio gives an indication of the fraction of the lobe, which is covered twice; i.e. how much the lobe is being offset from its previous position by change in the torpedo course. The question of offsetting the sonar lobe, about which information is given in the printout, is discussed later in Ch. VI.

Ref. Fig. 8.

For each run, the following are output: target data, torpedo deflection angle, torpedo main course, target and torpedo grid position at end of run, duration of torpedo run and length of torpedo run.

After all runs in a series are completed, a summary is given.

Ref. Fig. 9.

The summary gives detection probability for a single detection, 2 successive detections, up to 5 successive detections. Also mean detection range, standard deviation of detection range, mean aspect, mean detection bearing relative to center bearing of sonar lobe and relative to main course are given.

Lastly, the detection range, the relative bearing to the center of the target and to the closest part of the target

TACTICAL SITUATION WHEN FIRING				TORPEDO PARAMETER						
RANGE	ATTACK ANGLE	TARGET COURSE	TARGET SPEED	TEC.DET RANGE	TORP SPEED	SWEEP ANGLE	LOBE WIDTH	TURN RATE	SWEEP LANE	COVERAGE RATIO
3000.	-90.0	270.0	18.0	750.0	40.0	30.0	20.0	18.0	1143.1	0.550

SONAR MAIN LOBE OFF-SET FROM CENTER BEARING 0.0 TIMES DEFLECTION ANGLE

RUN NO	EST OF TARGET COURSE	SPEED	RANGE	TORP DA	TORP M COURSE	TORP COORD X	Y	TARGET COORD X	Y	RUN STOP	TORP RUN
1	256.5	12.4	3345.	-17.5	342.5	14037.	15061.	13488.	15000.	163	3360.
NO DETECTION MADE DURING THIS RUN											
2	256.5	14.2	2792.	-20.1	339.9	13825.	15199.	13394.	15000.	178	3570.
NO DETECTION MADE DURING THIS RUN											
3	256.5	15.1	2980.	-21.5	338.5	13755.	15173.	13394.	15000.	178	3570.
NO DETECTION MADE DURING THIS RUN											
4	256.5	15.8	2912.	-22.6	337.4	13695.	15149.	13394.	15000.	178	3570.
NO DETECTION MADE DURING THIS RUN											
5	256.5	16.4	3232.	-23.5	336.5	13634.	15122.	13394.	15000.	178	3570.
NO DETECTION MADE DURING THIS RUN											
6	256.5	17.0	3392.	-24.4	335.6	13597.	15106.	13394.	15000.	178	3570.
7	256.5	17.5	2922.	-25.2	334.8	13450.	15259.	13299.	15000.	189	3780.
8	256.5	18.0	3438.	-25.9	334.1	13434.	15251.	13299.	15000.	189	3780.
9	256.5	18.5	3312.	-26.7	333.3	13366.	15218.	13299.	15000.	189	3780.
10	256.5	19.0	2931.	-27.5	332.5	13342.	15206.	13299.	15000.	189	3780.
11	256.5	19.6	2948.	-28.4	331.6	13269.	15167.	13299.	15000.	189	3780.
12	256.5	20.2	3394.	-29.4	330.6	13241.	15151.	13299.	15000.	189	3780.
13	256.5	20.9	2897.	-30.5	329.5	13154.	15101.	13299.	15000.	189	3780.
NO DETECTION MADE DURING THIS RUN											
14	256.5	21.8	2818.	-32.1	327.9	12977.	15229.	13205.	15000.	199	3990.
NO DETECTION MADE DURING THIS RUN											
15	256.5	23.6	3230.	-35.0	325.0	12813.	15119.	13205.	15000.	199	3990.
NO DETECTION MADE DURING THIS RUN											
16	259.5	12.4	3430.	-17.7	342.3	14033.	15058.	13488.	15000.	168	3360.
NO DETECTION MADE DURING THIS RUN											
17	259.5	14.2	3277.	-20.4	339.6	13816.	15195.	13394.	15000.	178	3570.
NO DETECTION MADE DURING THIS RUN											
18	259.5	15.1	3354.	-21.8	338.2	13733.	15163.	13394.	15000.	178	3570.
NO DETECTION MADE DURING THIS RUN											
19	259.5	15.8	3368.	-22.9	337.1	13670.	15137.	13394.	15000.	178	3570.
NO DETECTION MADE DURING THIS RUN											
20	259.5	16.4	3282.	-23.8	336.2	13626.	15118.	13394.	15000.	178	3570.
21	259.5	17.0	2964.	-24.7	335.3	13581.	15098.	13394.	15000.	178	3570.
22	259.5	17.5	2793.	-25.5	334.5	13460.	15263.	13299.	15000.	189	3780.
23	259.5	18.0	2843.	-26.3	333.7	13389.	15229.	13299.	15000.	189	3780.
24	259.5	18.5	3260.	-27.1	332.9	13369.	15218.	13299.	15000.	189	3780.
25	259.5	19.0	2853.	-27.9	332.1	13325.	15196.	13299.	15000.	189	3780.
26	259.5	19.6	3338.	-28.3	331.2	13250.	15155.	13299.	15000.	189	3780.
27	259.5	20.2	2790.	-29.7	330.3	13198.	15127.	13299.	15000.	189	3780.
NO DETECTION MADE DURING THIS RUN											
28	259.5	20.9	3384.	-30.9	329.1	13132.	15088.	13299.	15000.	189	3780.
NO DETECTION MADE DURING THIS RUN											
29	259.5	21.6	2904.	-32.5	327.5	12963.	15213.	13205.	15000.	199	3990.

Figure 8 - EXAMPLE OF PRINTOUT READING

```
140    283.5  16.4  2957.   -23.5   336.5      13630. 15121.  13394. 15000.    178    3570.
141    283.5  17.0  2891.   -24.4   335.6      13600. 15107.  13394. 15000.    178    3570.
142    283.5  17.5  2978.   -25.2   334.8      13554. 15087.  13394. 15000.    178    3570.
143    283.5  18.0  3231.   -25.9   334.1      13435. 15250.  13299. 15000.    189    3780.
144    283.5  18.5  2908.   -26.7   333.3      13366. 15218.  13299. 15000.    189    3780.
145    283.5  19.0  2985.   -27.5   332.5      13318. 15193.  13299. 15000.    189    3780.
146    283.5  19.6  3321.   -28.4   331.6      13295. 15180.  13299. 15000.    189    3780.
147    283.5  20.2  2915.   -29.4   330.6      13217. 15138.  13299. 15000.    189    3780.
148    283.5  20.9  3379.   -30.5   329.5      13153. 15100.  13299. 15000.    189    3780.
NO DETECTION MADE DURING THIS RUN
149    283.5  21.8  2815.   -32.1   327.9      12978. 15229.  13205. 15000.    199    3990.
NO DETECTION MADE DURING THIS RUN
150    283.5  23.6  3380.   -35.0   325.0      12811. 15117.  13205. 15000.    199    3990.
NO DETECTION MADE DURING THIS RUN

     SUMMARY OF RESULT AFTER    150  RUNS
         PROBABILITY OF DETECTION          AVERAGE     STD DEVIATION     AVERAGE        AVERAGE       AVERAGE
                                           DET RANGE   DET RANGE         TARGET ASPECT  DET BEARING   REL BEARING
ONE SUCCESSIVE DETECTION          0.4933   289.0916    113.0052          106.5719       12.2924        9.8401
TWO SUCCESSIVE DETECTIONS         0.4067   232.0447    113.0933          104.3547       21.5057       12.3818
THREE SUCCESSIVE DETECTIONS       0.2933   186.8285     99.5317          104.6071       23.9137       12.3860
FOUR SUCCESSIVE DETECTIONS        0.2467   144.6790     80.2721           99.3172       33.0407       17.9134
FIVE SUCCESSIVE DETECTIONS        0.1933   126.7648     44.6235          113.0907       22.7728        3.9739

AVERAGE DEFLECTION ANGLE :     -26.5123

DISTRIBUTION OF RUN RESULT - CENTER OF TARGET
     ONE SUCCESSIVE DETECTION            TWO SUCCESSIVE DETECTIONS            THREE SUCCESSIVE DETECTIONS
 BEAR   RANGE  ASPECT  BEAR CLOS      BEAR   RANGE  ASPECT  BEAR CLOS      BEAR   RANGE  ASPECT  BEAR CLOS
   0.0    0.0     0.0    0.0           0.0    0.0     0.0    0.0            0.0    0.0     0.0    0.0
   0.0    0.0     0.0    0.0           0.0    0.0     0.0    0.0            0.0    0.0     0.0    0.0
   0.0    0.0     0.0    0.0           0.0    0.0     0.0    0.0            0.0    0.0     0.0    0.0
   0.0    0.0     0.0    0.0           0.0    0.0     0.0    0.0            0.0    0.0     0.0    0.0
   0.0    0.0     0.0    0.0           0.0    0.0     0.0    0.0            0.0    0.0     0.0    0.0
   3.4  295.0  -128.2   11.8           0.0    0.0     0.0    0.0            0.0    0.0     0.0    0.0
   1.7  288.6  -119.3   11.0           0.7  184.1  -141.8   12.7          -13.5  171.3  -143.7   -0.9
  -9.4  386.1  -104.8   -2.0          11.2  227.8  -121.4   23.1          -14.4  130.8  -152.0    0.6
  -0.5  448.1   -97.6    5.9          -8.6  348.4   -99.4   -0.4           -1.0  330.1  -101.2    7.7
  19.8  273.3   -97.7   19.8          36.7  254.7   -94.1   36.7           -7.7  174.1  -103.3    8.9
  47.3  171.5   -80.9   15.1          31.9  153.1   -80.2   -3.9           35.8  132.3   -81.9   36.9
  19.4  228.7   -75.1    6.7          76.4   99.3   -57.4   27.6            0.0    0.0     0.0    0.0
   0.0    0.0     0.0    0.0           0.0    0.0     0.0    0.0            0.0    0.0     0.0    0.0
   0.0    0.0     0.0    0.0           0.0    0.0     0.0    0.0            0.0    0.0     0.0    0.0
   0.0    0.0     0.0    0.0           0.0    0.0     0.0    0.0            0.0    0.0     0.0    0.0
   0.0    0.0     0.0    0.0           0.0    0.0     0.0    0.0            0.0    0.0     0.0    0.0
   0.0    0.0     0.0    0.0           0.0    0.0     0.0    0.0            0.0    0.0     0.0    0.0
   0.0    0.0     0.0    0.0           0.0    0.0     0.0    0.0            0.0    0.0     0.0    0.0
   0.0    0.0     0.0    0.0           0.0    0.0     0.0    0.0            0.0    0.0     0.0    0.0
  -6.2  258.3  -149.9    0.4           0.0    0.0     0.0    0.0            0.0    0.0     0.0    0.0
   4.8  292.1  -125.2   13.6         -11.1  193.2  -148.6   -1.6            0.0    0.0     0.0    0.0
  -3.8  245.9  -124.8    6.9          11.6  231.3  -127.0   22.8            6.7  217.1  -127.9   18.6
 -12.0  442.9   -99.6   -5.6           4.0  424.8  -101.1   10.7           23.1  107.6  -122.4   34.8
   6.9  383.7   -98.4   14.3          -9.6  284.3  -100.5    0.5            5.4  266.3  -103.0   16.2
  24.4  161.7   -97.8   24.4          41.0  143.3  -100.3   41.0          -14.6   63.1  -104.7  -14.6
  28.0  282.6   -81.3    8.2          13.6  262.6   -81.7    2.6           50.7  125.7   -75.8   17.1
   0.0    0.0     0.0    0.0           0.0    0.0     0.0    0.0            0.0    0.0     0.0    0.0
   0.0    0.0     0.0    0.0           0.0    0.0     0.0    0.0            0.0    0.0     0.0    0.0
   0.0    0.0     0.0    0.0           0.0    0.0     0.0    0.0            0.0    0.0     0.0    0.0
```

Figure 9 - EXAMPLE OF PRINTOUT SUMMARY

at detection (relative to present torpedo course), and the target aspect at detection are printed for each run for a single detection, 2 successive and 3 successive detections.

It also should be noted that it is possible to get a more detailed printout for each run by setting IPRINT = 0 in the main program (main program statement 035).
Ref. Appendix D. for example of detailed run printout.

From the printout data, it is possible to study different aspects of the detection process as well as to generate distributions of detection range, aspect, bearing etc.

VI. PARAMETRIC TORPEDO ANALYSIS

A. OBJECTIVES

The following approach was used:
The torpedo speed, the technical detection range and the lobe width were assumed to characterize a torpedo type. Within the type, it was possible to change the turn rate and the sweep angle.

A tactical situation was characterized by the attack angle, the target speed and the firing range.

The following questions were investigated:

- Can a torpedo be improved by offsetting its sonar lobe from the torpedo heading ?
  Rephrased; it may be asked, is the sonar lobe searching in the right direction (most likely area) by pointing straight ahead along the torpedo course ?
- How do turn rate and sweep angle affect a torpedo's MOE ?
- How are the different torpedo types related to each other with regard to detection probability (MOE) ?

In the analysis, we started with a reasonable tactical situation; target speed 18 knots, range 3000 meters, technical detection range 750 meters. Initially, we changed the attack angles.
With regard to torpedoes, we started with three types of

torpedoes; 24 knots, 32 knots and 40 knots; all with 20 degree lobe width, 6 degree per second turn rate and 30 degree sweep angle.

B. OFFSETTING SONAR LOBE

The hypothesis was that when a torpedo is fired on a deflection angle course, the sonar lobe should be most effective if it scans across the bearing to the target.
Or, the sonar lobe should be offset equal to deflection angle (DA). Ref. Fig. 10.

It was found that offsetting had a positive effect when attacking from ahead of target.
Ref. Fig. 11.a. and b.
But from about 30 degree to about 110 degree attack angle the effect was negative. If more than 110 degree attack angle, there was no effect.

In analyzing the fraction of offsetting, we analyzed the case of 30 degree and 60 degree attack angle. There seemed to be no effect from 0.0 to 0.5 x DA; if more than 0.5 x DA there was a decreasing efficiency.
This was found for 2 types of torpedoes (32 and 40 knots; 20 degree lobe width) at 2 different sets of turn rates and sweep angles.

This conclusion applies for both single detection and multiple successive detections; however, the magnitude of the effect is changing as we look on different number of successive detections. The conclusion was that there is

little to be gained by offsetting the sonar lobe, and the sonar lobe was therefore not offset in subsequent investigations.

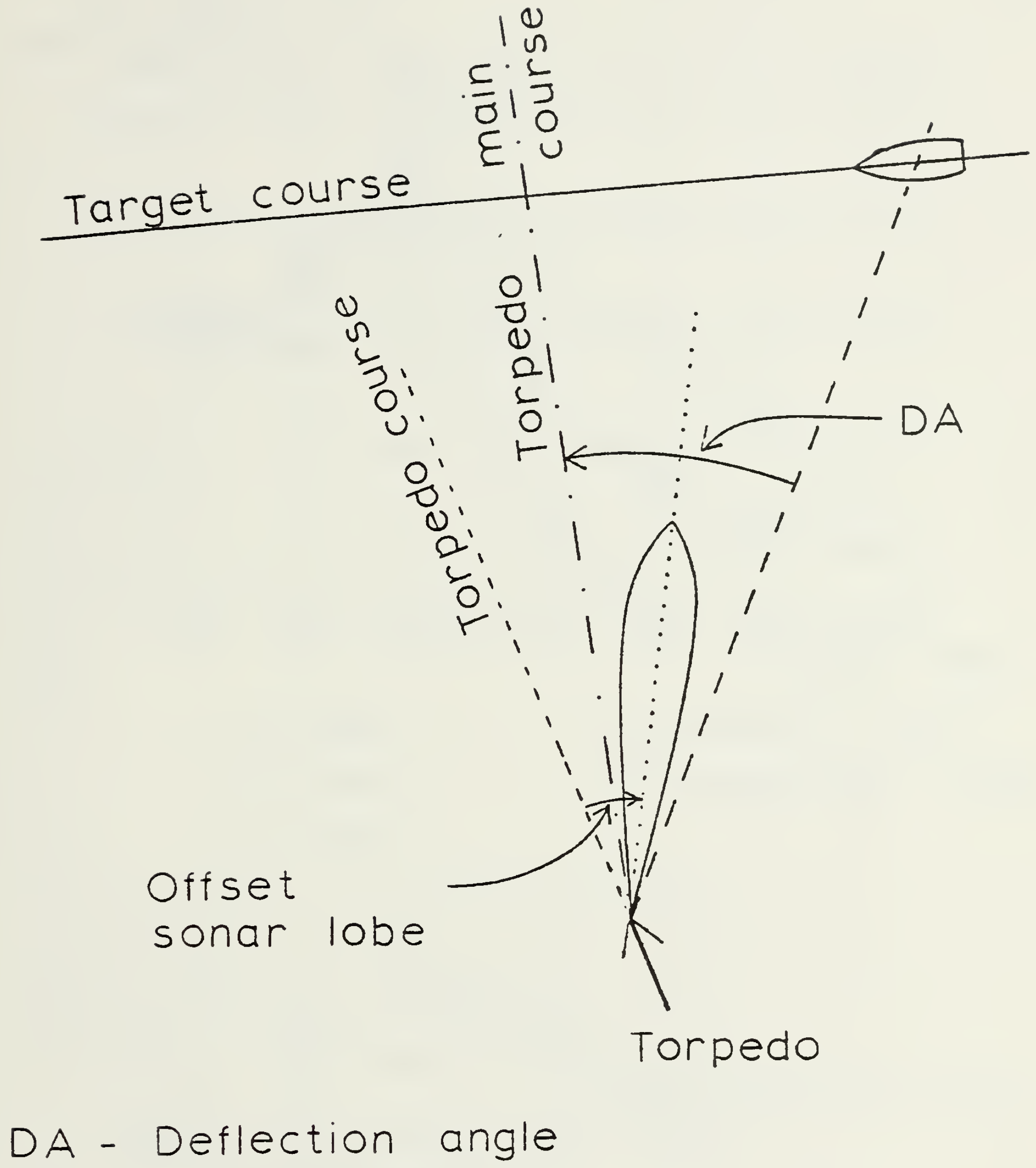


Figure 10 - OFFSET SONAR LOBE

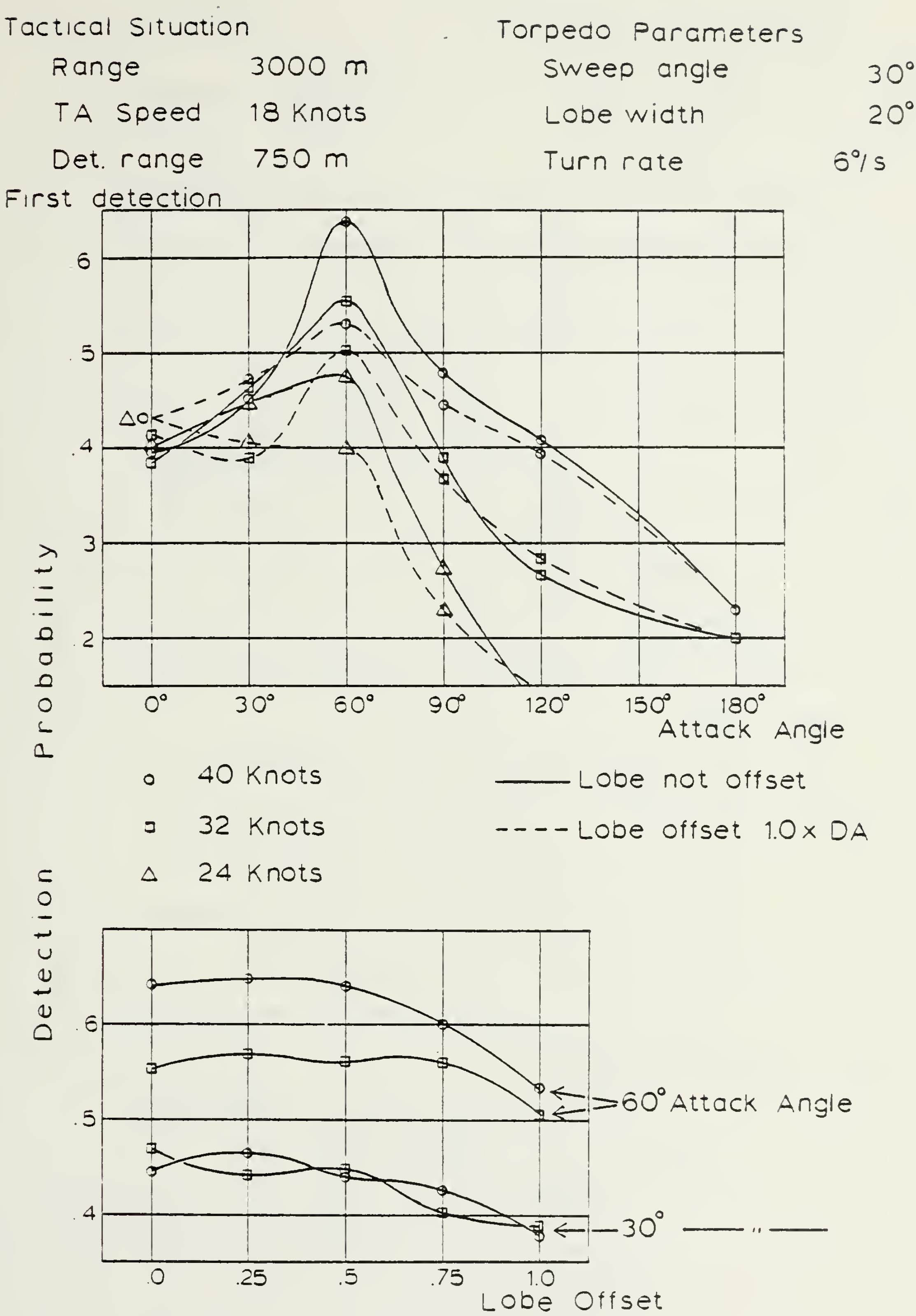


Figure 11 - EFFECT OF OFFSETTING SONAR LOBE

Tactical Situation

Range	3000 m
TA Speed	18 Knots
Det range	750 m

Torpedo Parameters

Sweep angle	30°
Lobe width	20°
Turn rate	6°/s

Two detections

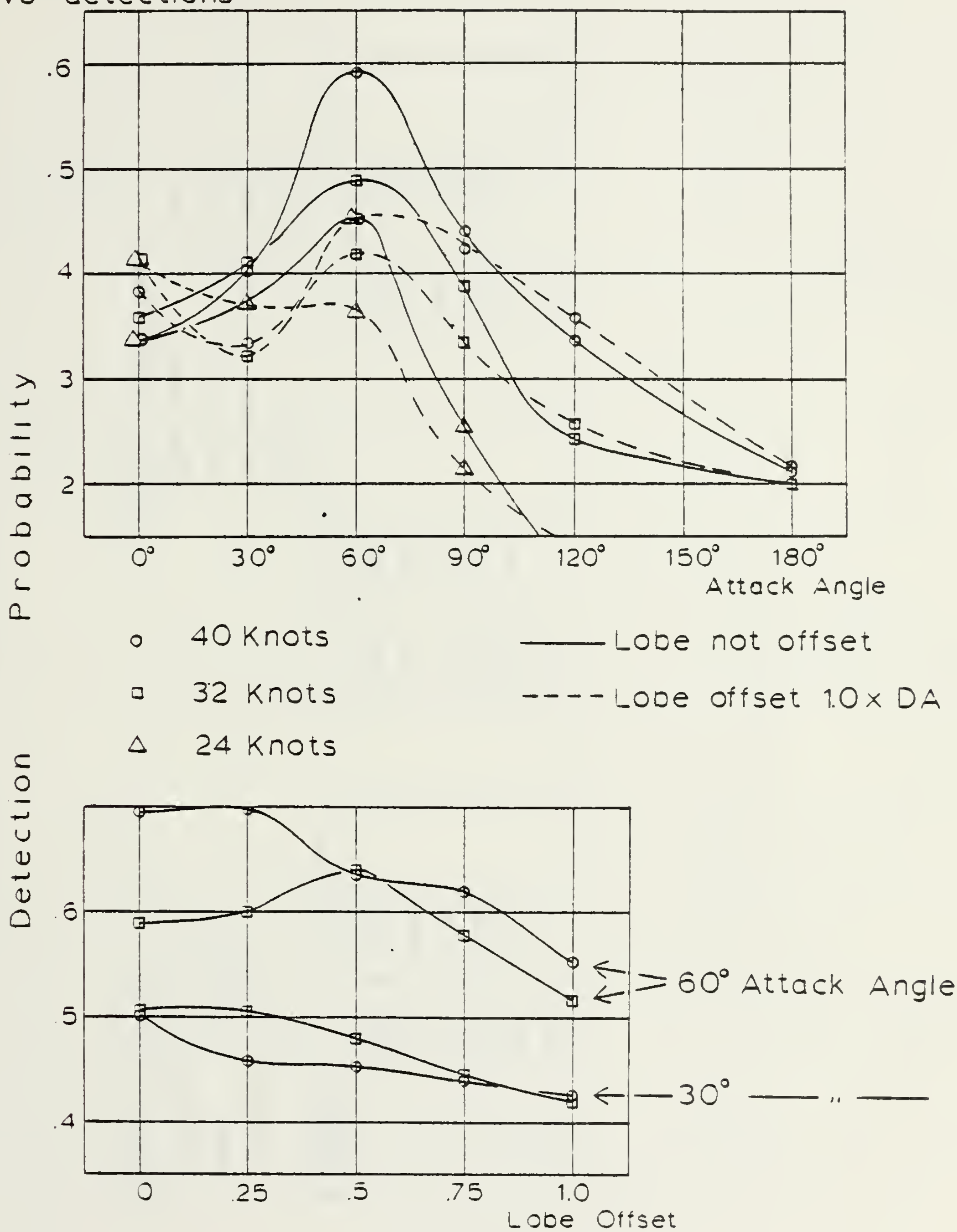


Figure 11.b. - EFFECT OF OFFSETTING SONAR LOBE

Tactical situation

Target speed 18 knots

Range 3000 m

Detection range 750 m

Torpedo parameters

.Torpedo speed 24 knots

Sweep angle 30 degrees

Lobe width 20 degrees

Turn rate 6 deg/sec

Attack angle	1 detection				2 detections				3 detections				Offset lobe
	0.0	1.0			0.0	1.0			0.0	1.0			x DA
0	.4000	.4333			.3303	.4067			.3133	.3400			
30	.4467	.4067			.3733	.3667			.3200	.3133			
60	.4733	.4000			.4533	.3667			.4267	.3333			
90	.2733	.2267			.2533	.2133			.2400	.1867			
120	.1200	.1467			.1133	.1467			.1133	.1200			
180	.0000				.0000				.0000				

Table I - VARIATION IN OFFSETTING SONAR LOBE

Tactical situation

Target speed 18 knots

Range 3000 m

Detection range 750 m

Torpedo parameters

Torpedo speed 32 knots

Sweep angle 30 degrees

Lobe width 20 degrees

Turn rate 6 deg/sec

Attack angle	1 detection				2 detections				3 detections				Offset lobe
	0.0	0.25	0.5	0.75	0.0	0.25	0.5	0.75	0.0	0.25	0.5	0.75	x DA
0	.3867				.3600				.2800				
30	.4667	.4400	.4467	.4000	.4067	.4067	.3800	.3467	.3400	.3067	.2867	.2733	
60	.5533	.5667	.5600	.6600	.4867	.5000	.5400	.4800	.4333	.4600	.4333	.4133	
90	.3933				.3867				.3067				
120	.2667				.2400				.2133				
180	.2000				.2000				.2000				

Tactical situation

Torpedo parameters

Attack angle	1 detection				2 detections				3 detections				Offset lobe
	1.0				1.0				1.0				x DA
0	.4267				.4067				.2733				
30	.3867				.3200				.2733				
60	.5067				.4200				.3600				
90	.3667				.3267				.3000				
120	.2800				.2533				.2400				
180	.2000				.2000				.2000				

Table I.b. - VARIATION IN OFFSETTING SONAR LOBE

Tactical situation

Target speed 18 knots
Range 3000 m
Detection range 750 m

Torpedo parameters

Torpedo speed 40 knots
Sweep angle 30 degrees
Lobe width 20 degrees
Turn rate 6 deg/sec

Attack angle	1 detection				2 detections				3 detections				Offset lobe
	0.0	0.25	0.5	0.75	0.0	0.25	0.5	0.75	0.0	0.25	0.5	0.75	
0	.3933				.3333				.2533				x DA
30	.4467	.4667	.4400	.4267	.4000	.3533	.3533	.3400	.3533	.3200	.3067	.2933	
60	.6400	.6467	.6400	.5867	.5933	.6000	.5333	.5200	.5400	.4733	.4200	.4000	
90	.4733				.4400				.3933				
120	.4067				.3400				.2800				
180	.2267				.2133				.2000				

Tactical situation

Torpedo parameters

Attack angle	1 detection				2 detections				3 detections				Offset lobe
	1.0				1.0				1.0				
0	.4333				.3800				.2733				x DA
30	.3733				.3267				.2733				
60	.5333				.4533				.4067				
90	.4467				.4200				.3600				
120	.3933				.3600				.3333				
180	.2333				.2200				.2000				

Table I.c. - VARIATION IN CFFSETTING SONAR LOBE

C. EFFECT OF TURN RATE

The effect of turn rate was investigated in the range 3 to 21 degrees per second in steps of 3. For both types of torpedoes the model showed an increase in MOE as turn rate was increased. The MOE leveled off as turn rate was approaching 15 - 20 degrees per second.

The reason may be due to the 1 second transmission interval and the 20 degree lobe width, which indicates that the torpedo should be turned at a turn rate equal to lobe width divided by transmission interval for maximum MOE. However, as the number of successive detections required is increased, we get maximum MOE at lower turn rates.
Fig. 12 shows the change in MOE with turn rate for 30 and 60 degrees attack angles.
From Fig. 15 where different combinations of turn rates and sweep angles are plotted versus MOE, we see that the effect is negligible from about 60-80 degrees to 180 degrees attack angle.

A 6 degrees per second turn rate is compared with what may be termed an 'optimal' turn rate in Fig. 13. The 'optimal' turn rates were established by the general trend from Fig. 12 and Table II.a and II.b.
The following turn rates were identified as 'optimal';

- 15 degrees per second for the 32 knots torpedo
- 18 degrees per second for the 40 knots torpedo.

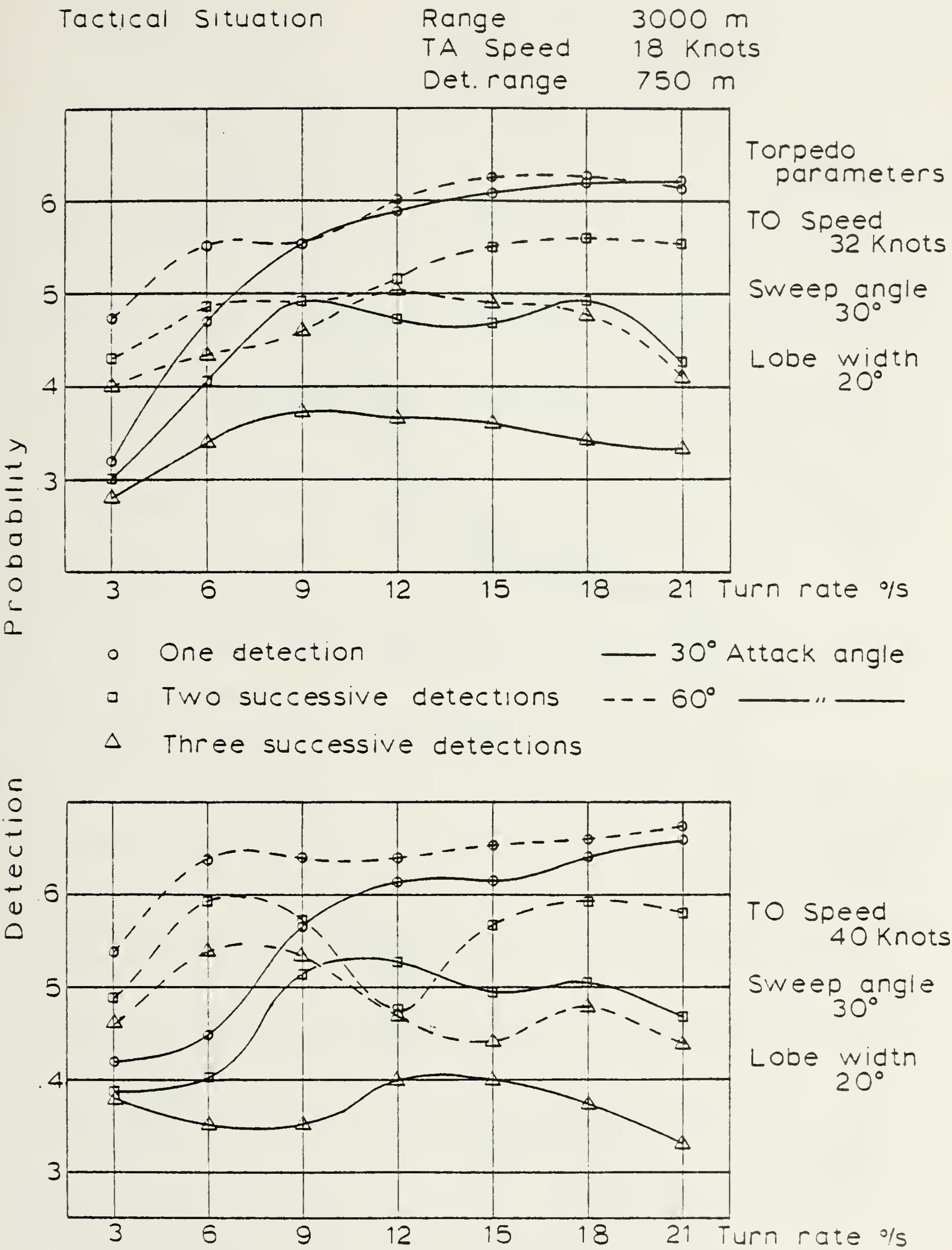


Figure 12 - EFFECT OF TURN RATE

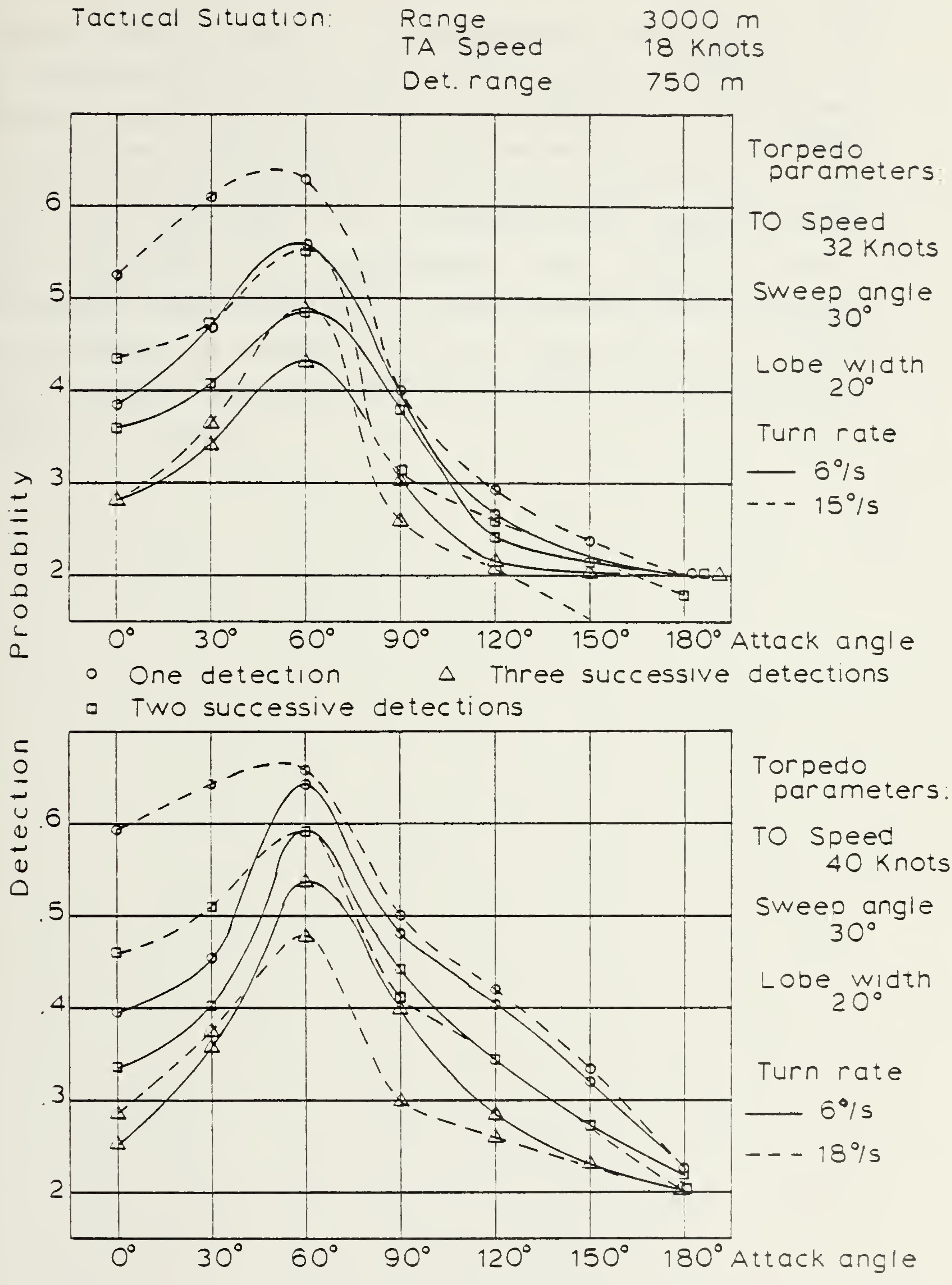


Figure 13 - COMPARISON OF TORPEDOES WITH DIFFERENT TURN RATES

We see here in Fig. 13 a considerable increase in MOE with increase in turn rate for attack angles less than 60 - 80 degrees for single detection; an consistent improvement for 2 successive detections in the same area; but no change or a slight detoriation for 3 successive detections.
It is quite obvious that a torpedo which requires only a single detection as requirement for attack has a considerably better MOE, and a considerably higher potential for improvement by changes in turn rate, than a torpedo which requires more successive detections for classifying a contact as a target.

Tactical situation

Target speed 18 knots

Range 3000 m

Detection range 750 m

Torpedo parameters

Torpedo speed 40 knots

Sweep angle 30 degrees

Lobe width 20 degrees

Attack angle	1 detection				2 detections				3 detections				Turn rate deg/sec
	3	6	9	12	3	6	9	12	3	6	9	12	
0		.3933		.5733		.3333		.4600		.2533		.2667	
30	.4200	.4467	.5667	.6133	.3867	.4000	.5133	.5267	.3800	.3533	.3533	.4000	
60	.5333	.6400	.6400	.6400	.4867	.5933	.5733	.4667	.4600	.5400	.5333	.4667	
90		.6400		.4733		.4400		.4400		.3933		.3600	
120		.4067				.3400				.2800			
180		.2267				.2133				.2000			

Tactical situation

Torpedo parameters

Attack angle	1 detection				2 detections				3 detections				Turn rate deg/sec
	12	15	18	21	12	15	18	21	12	15	18	21	
0	.5733		.5933		.4600		.4600		.2667		.2867		
30	.6133	.6133	.6400	.6600	.5267	.4933	.5067	.4667	.4000	.4000	.3733	.3300	
60	.6400	.6533	.6600	.6733	.4667	.5667	.5933	.5800	.4667	.4400	.4800	.4400	
90	.4733		.4933		.4400		.4067		.3600		.2933		
120			.4200				.3467				.2600		
180			.2267				.2000				.2000		

Table II.b. - VARIATION IN TORPEDO TURN RATE

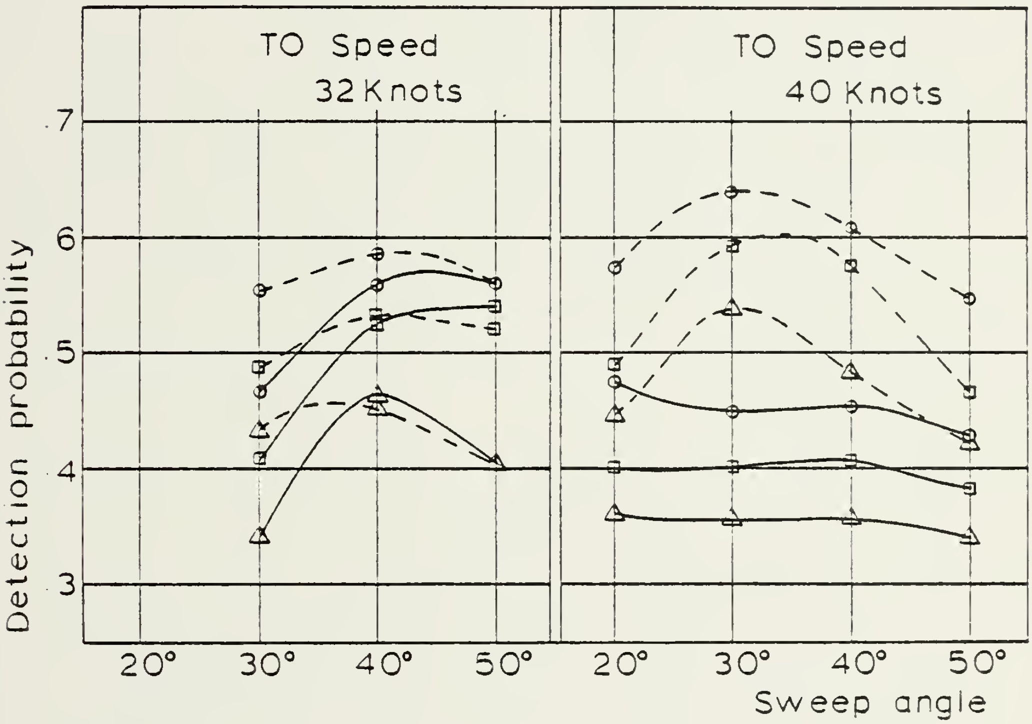
D. EFFECT OF SWEEP ANGLE

From preliminary simulation runs, it was found that from 90 degrees (inclusive) to 180 degrees attack angle the effect of the sweep angle was neglegible. The analysis was therefore done from 20 to 50 degrees sweep angle only for 30 and 60 degrees attack angle for both the 32 and the 40 knots torpedo.
The result is shown in Fig. 14.

For the 32 knot torpedo we get an increase from 30 to 40 degrees for both attack angles. From 40 to 50 degrees, MOE either levels off or decrease slowly. As a conclusion, we established 40 degrees sweep angle as the 'optimal' value. For the 40 knot torpedo, the MOE was fairly steady over the whole range for 30 degrees attack angle. For 60 degrees attack angle, there was a peak at 30 degrees sweep angle, which indicated that 30 degrees was the optimal value.

The reason for the different sweep angles for the two torpedo types (Note; both have 6 degrees per second turn rate) may be due to the time it takes to reach the target. The shorter time,the less area on each side of the main course is needed to be covered in order to detect a target; i.e. a 40 knot torpedo needs only a 30 dergree sweep angle, a 32 knot torpedo needs 40 degree sweep angle.

Tactical Situation.	Range	3000 m
	TA Speed	18 Knots
	Det. range	750 m
Torpedo Parameters:	Lobe width	20°
	Turn rate	6°/s



○ One detection

□ Two successive detections

△ Three successive detections

——— 30° Attack angle

- - - 60° ——— " ———

Figure 14 - EFFECT OF SWEEP ANGLE

The reason why we get a peak and then a reduction in MOE as we increase sweep angle is supposedly due to a sharp decrease in speed along the main course as sweep angle is approaching 60 degrees.
As example, for a 40 knots torpedo the model gave 35 knots along main course for 50 degrees sweep angle as compared with 38.6 knots for 20 degrees sweep angle. For a slower torpedo, the effect on MOE may be considerable due to less speed advantage relative to the target.

Tactical situation

Target speed 18 knots

Range 3000 m

Detection range 750 m

Torpedo parameters

Torpedo speed 32 knots

Lobe width 20 degrees

Turn rate 6 deg/sec

Attack angle	1 detection				2 detections				3 detections				Sweep angle degree
	20	30	40	50	20	30	40	50	20	30	40	50	
0		.3867	.3933			.3600	.3267			.2800	.2600		
30		.4667	.5600	.5600		.4067	.5267	.5400		.3400	.4600	.4067	
60		.5533	.5867	.5600		.4867	.5333	.5200		.4333	.4533	.4067	
90		.3933	.3733			.3867	.3733			.3067	.3400		
120		.2667	.2800			.2400	.2667			.2133	.2333		
180		.2000	.2000			.2000	.2000			.2000	.1867		

Tactical situation

Target speed 18 knots

Range 3000 m

Detection range 750 m

Torpedo parameters

Torpedo speed 40 knots

Lobe width 20 degrees

Turn rate 6 deg/sec

Attack angle	1 detection				2 detections				3 detections				Sweep angle degree
	20	30	40	50	20	30	40	50	20	30	40	50	
0		.3933				.3333				.2533			
30	.4733	.4467	.4533	.4267	.4000	.4000	.4067	.3800	.3600	.3533	.3533	.3400	
60	.5733	.6400	.6067	.4267	.5467	.5933	.5733	.4667	.4467	.5400	.4800	.4200	
90		.4733				.4400				.3933			
120		.4067				.3400				.2800			
180		.2267				.2133				.2000			

Table III - VARIATION IN SWEEP ANGLE

E. EFFECT OF BOTH SWEEP ANGLE AND TURN RATE

In the previous discussion we changed either sweep angle or turn rate for both types of torpedo while we kept the other variables constant.

In plotting MOE for initial torpedo (32 knots) value, optimal value for sweep angle, optimal value for turn rate and the 'optimal' torpedo (having both the 'optimal' turn rate and sweep angle), we get Fig. 15.
Observe how the MOE changes as we apply the individual 'optimal' values, and the MOE obtained by applying both the 'optimal' values.

At this stage, no trials were made in order to further increase MOE by changing sweep angle or turn rate from these values.

One essential feature is that virtually none of the variables so far have had any effect on MOE for larger attack angles than 60-90 degrees.

The relative difference in MOE between the 32 and the 40 knots torpedo types is shown in Fig. 16. Both torpedoes are optimal in the sense that the best values for turn rate and sweep angle have been choosen for that specific speed.

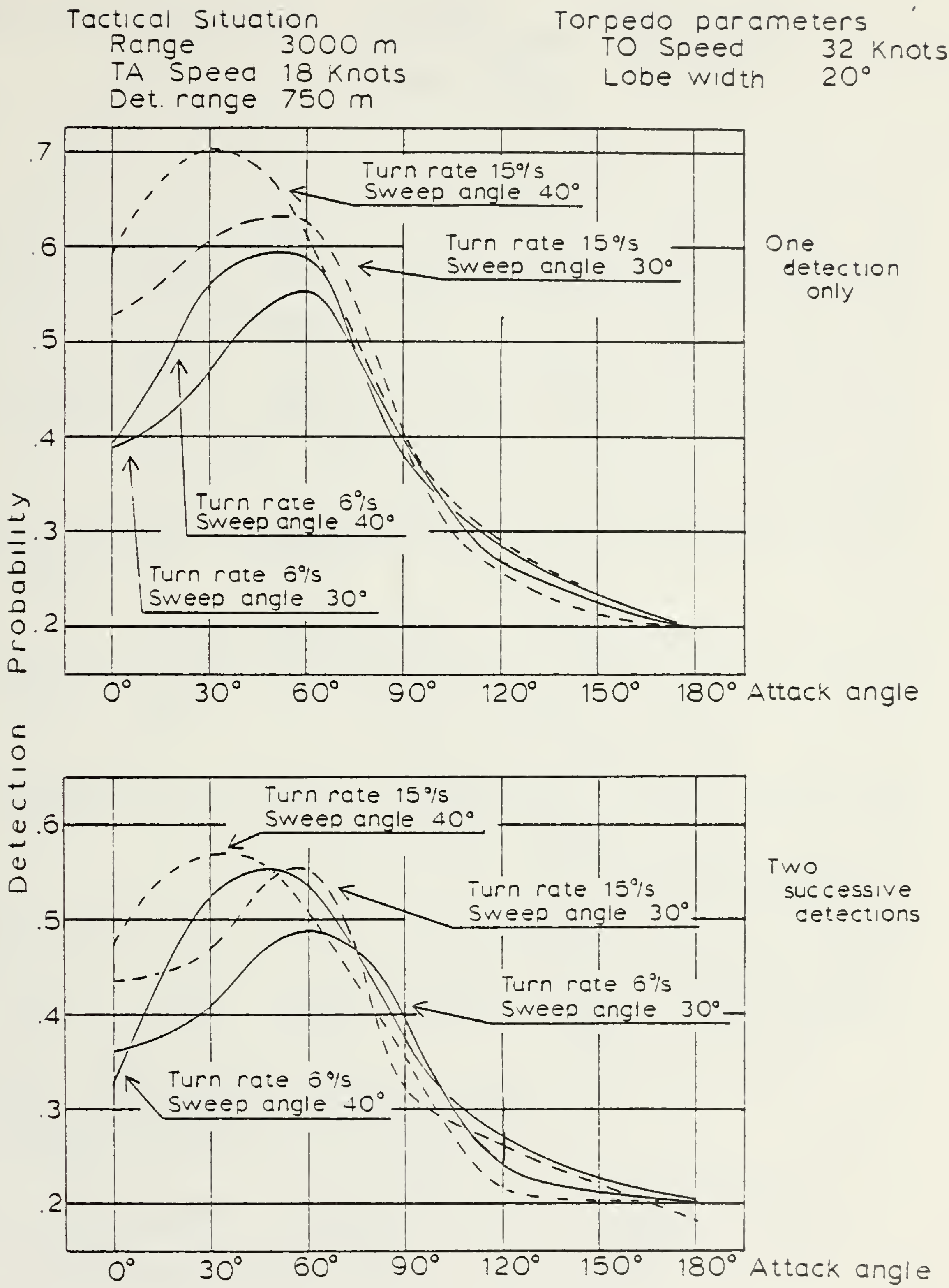


Figure 15 - COMPARISON OF DIFFERENT MODIFICATION OF A TORPEDO

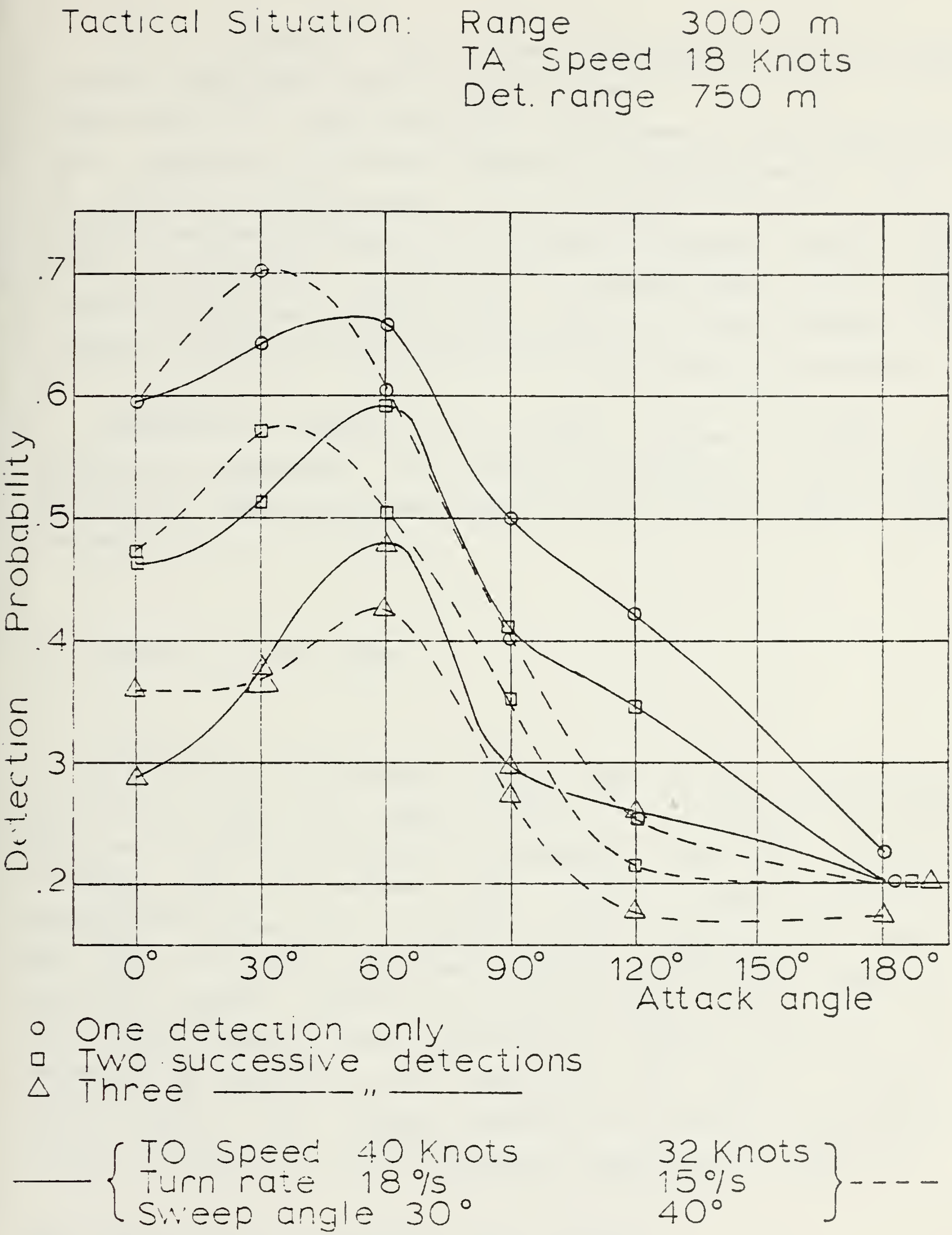


Figure 16 - COMPARISON OF TWO DIFFERENT TORPEDOES

It is obvious that the main differences are for large attack angles; more than 60-80 degrees.
Especially if the acquisition requirement is one detection only, however, a 32 knots torpedo is slightly better up to 60 degrees attack angle. This improved MOE for the slower torpedo may be explained by a better balance between the time to the target and the total relative speed. A toc high relative speed may prohibit the torpedo from getting the target within its sonar lobe before the target is passed.

Generally, however, the higher speed torpedo is superior, especially for larger attack angles (120 degrees and more); this can be explained by the shorter time to the target.

F. EFFECT OF LOBE WIDTH

The effect of changing lobe width while maintaining detection range is shown in Fig. 17. It should be noted that we initially started the simulation with an 'optimal' torpedo with 20 degrees lobe width. When we ran the simulation series for 10 degrees and 30 degrees lobe width, we did not change the other torpedo parameters in order to make the torpedo 'optimal' for the new lobe width. If we had carried through this optimization process, we might have expected an increase in the result for 10 and 30 degrees lobe width. The torpedo parameter in question would most likely be turn rate, ref discussion previously on page 61.

The interesting points from Fig. 17 are;

- a 10 degrees lobe width torpedo with a one-detection-only acquisition requirement is as good

as a 20 degrees lobe width torpedo with a two-successice-detection requirement. This should indicate what we have to pay in additional power transmitted when acquisition requirement is high. Or, where to invest research resources; in transducer or in echo filtering.

- the equally shaped curves for increasing lobe width. However, we also observe an increasing difference in MOE between the curves as attack angle is decreasing.
- the importance of the correct balance between turn rate and lobe width for successive detections. We observe for a small aspect target how MOE decreases drastically when we reduce lobe width from 20 degrees to 10 degrees and maintain turn rate and require two successive detections.

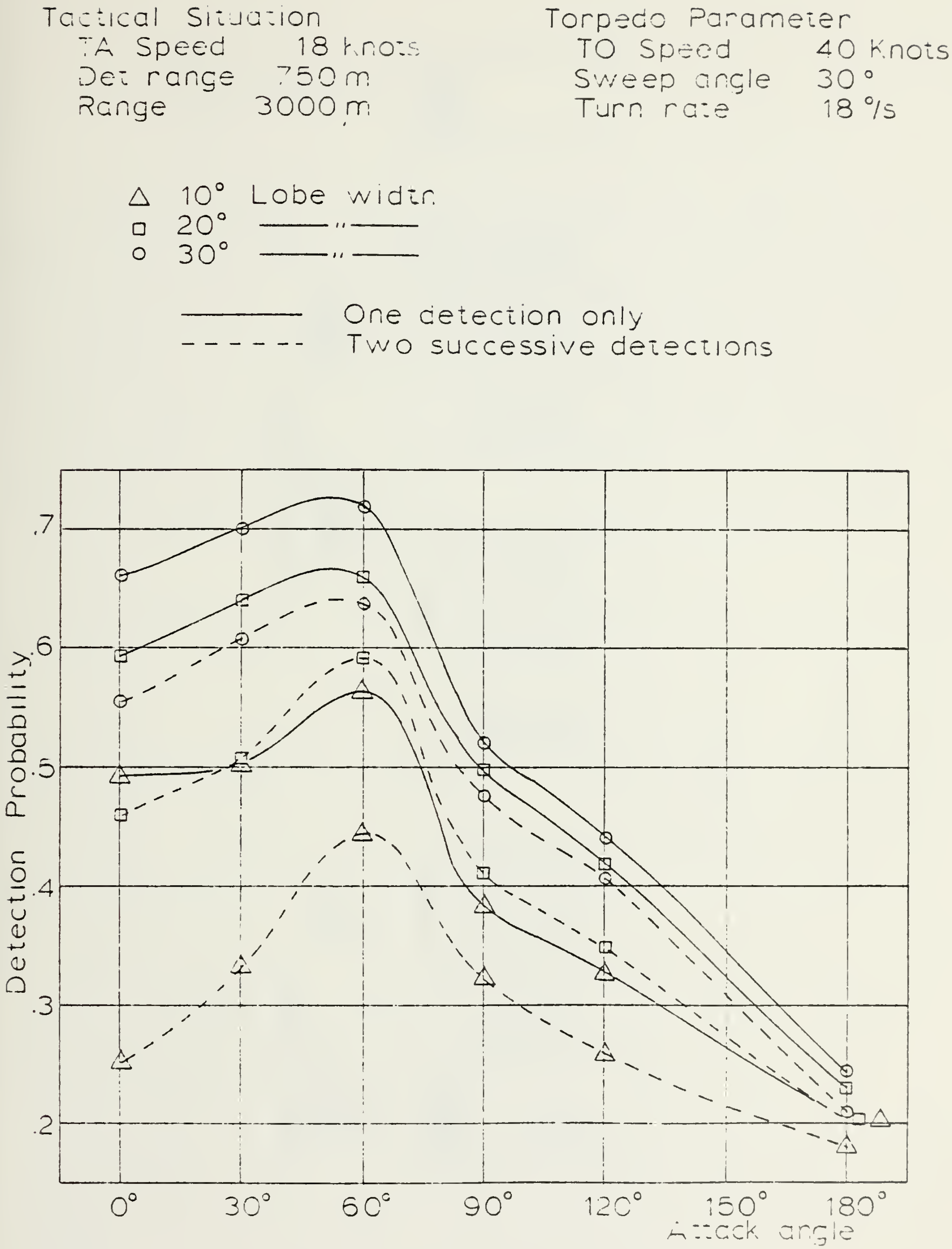


Figure 17 - EFFECT OF LOBE WIDTH

Tactical situation

Target speed	18 knots
Det.range	750 m
Range	3000 m

Torpedo parameters

Torpedo speed	40 knots
Sweep angle	30 degrees
Turn rate	18 deg/s

Attack angle	1 detection				2 detections				3 detections				Lobe width degrees
	10	20	30		10	20	30		10	20	30		
0	.4933	.5933	.6667		.2467	.4600	.5533		.1133	.2867	.4200		
30	.5000	.6400	.7000		.3267	.5067	.6067		.2333	.3733	.4800		
60	.5667	.6600	.7200		.4467	.5933	.6400		.3067	.4800	.5467		
90	.3800	.4933	.5133		.3200	.4067	.4733		.2267	.2933	.4000		
120	.3267	.4200	.4400		.2600	.3467	.4067		.1800	.2600	.3267		
180	.2000	.2267	.2400		.1800	.2000	.2067		.0867	.2000	.2000		

Table IV - VARIATION IN LOBE WIDTH

G. EFFECT OF DETECTION RANGE

The detection range is a function of the design of the active sonar in the torpedo as well as sonar condition at the time of the torpedo firing. The detection range as a function of the design of the active sonar is termed technical detection range. The detection range as a function of both the design and the sonar conditions is termed tactical detection range, or just detection range. In analyzing the detection probability as a function of detection range, we assumed optimal sonar conditions by equal technical detection range with detection range.

Detection range was varied in discrete steps: 375 - 750 - 1125 - 1500 meters.

Figs. 18.a. and b. indicate that detection probability is a linear function of the detection range up to a detection probability of 0.8 -0.9 for one detection. From the model, it may be justifiable to approximate the detection probability as a linear function from 375 m to 1125 m detection range.

From the model and the given assumptions, there is little usefulness in a homing torpedo with less than 300 m detection range.
The same situation is shown in Figs. 19.a. and b. in another cut of the response surface. We see here how consistantly the MOE has decreased over the whole range of attack angles when going from 1500 m to 375 m detection range.

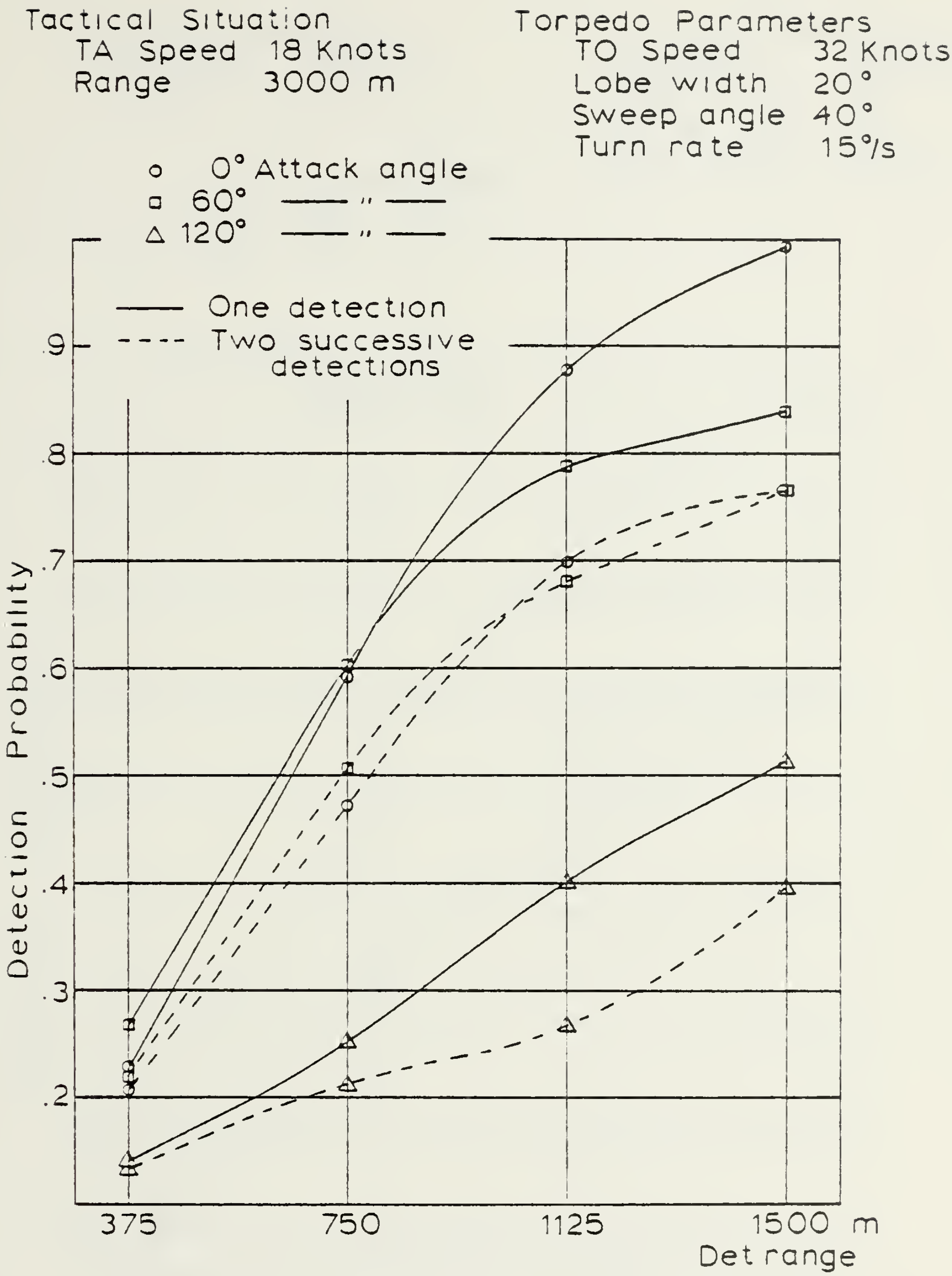


Figure 18 - EFFECT OF DETECTION RANGE

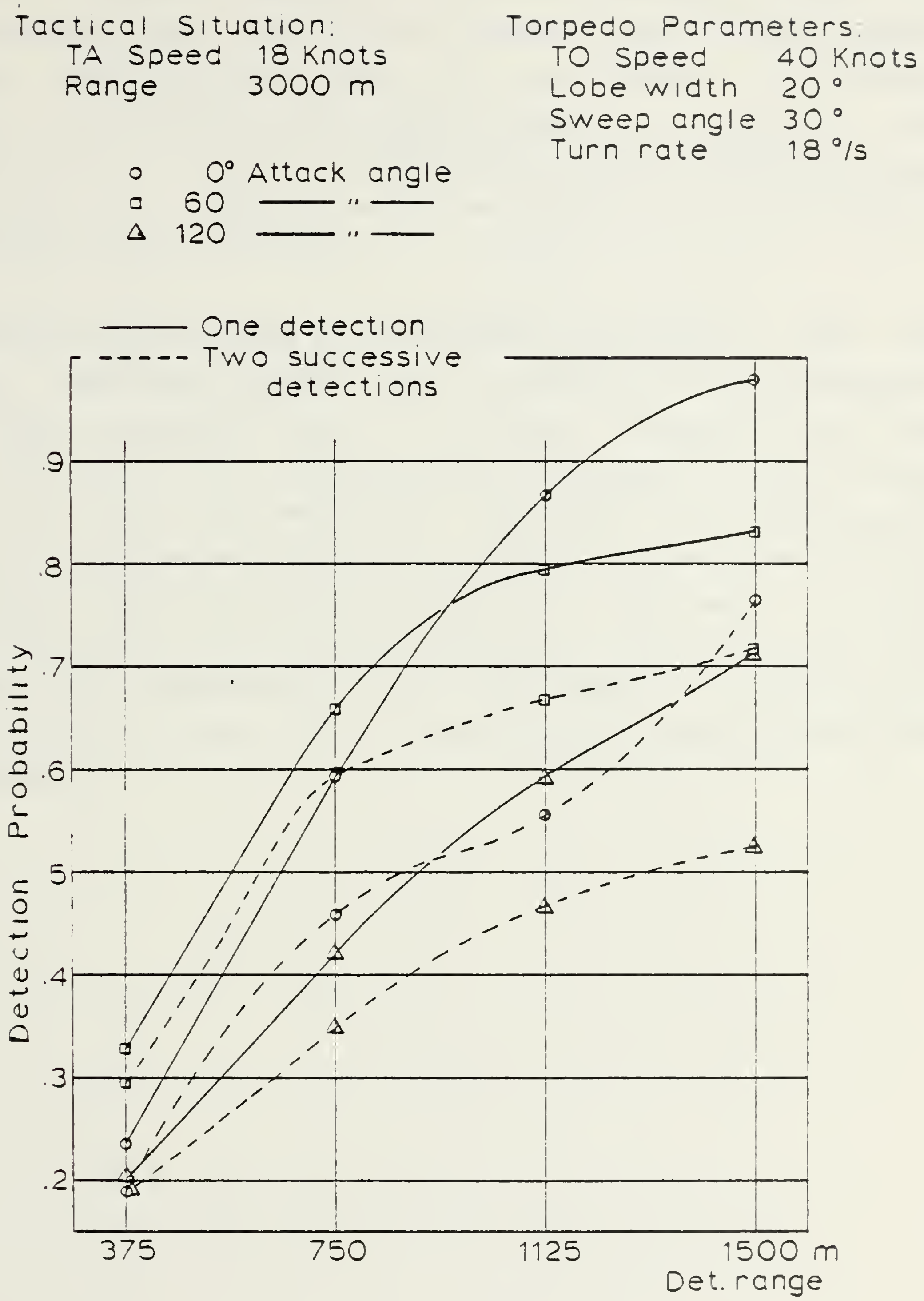


Figure 18.b. - EFFECT OF DETECTION RANGE

Otherwise the picture in Figs. 19.a. and b. is as in previous similar figures; a marked decrease in MOE with attack angles more than 60 - 90 degrees, and with the faster torpedo superior over most of the range. It should, however, be noted that for longer detection ranges we get maximum MOE at 0 degree attack angle for both torpedo types. This effect is reduced when we require two successive detections for acquisition.

We also experienced a considerable decrease in MOE for longer detection ranges when requiring two successive detections instead of one. It seems obvious that this reduction is due to a larger lateral movement at the extreme range. As noted previously, we increase the transmission interval (increase interval in order to allcw time for echo to return) when the detection range is increased. Keeping the same turn rate, the sonar lobe will turn a larger angle between each transmission, which can have a deteriorating effect on MOE for more than a one-detection-cnly acquisition requirement.

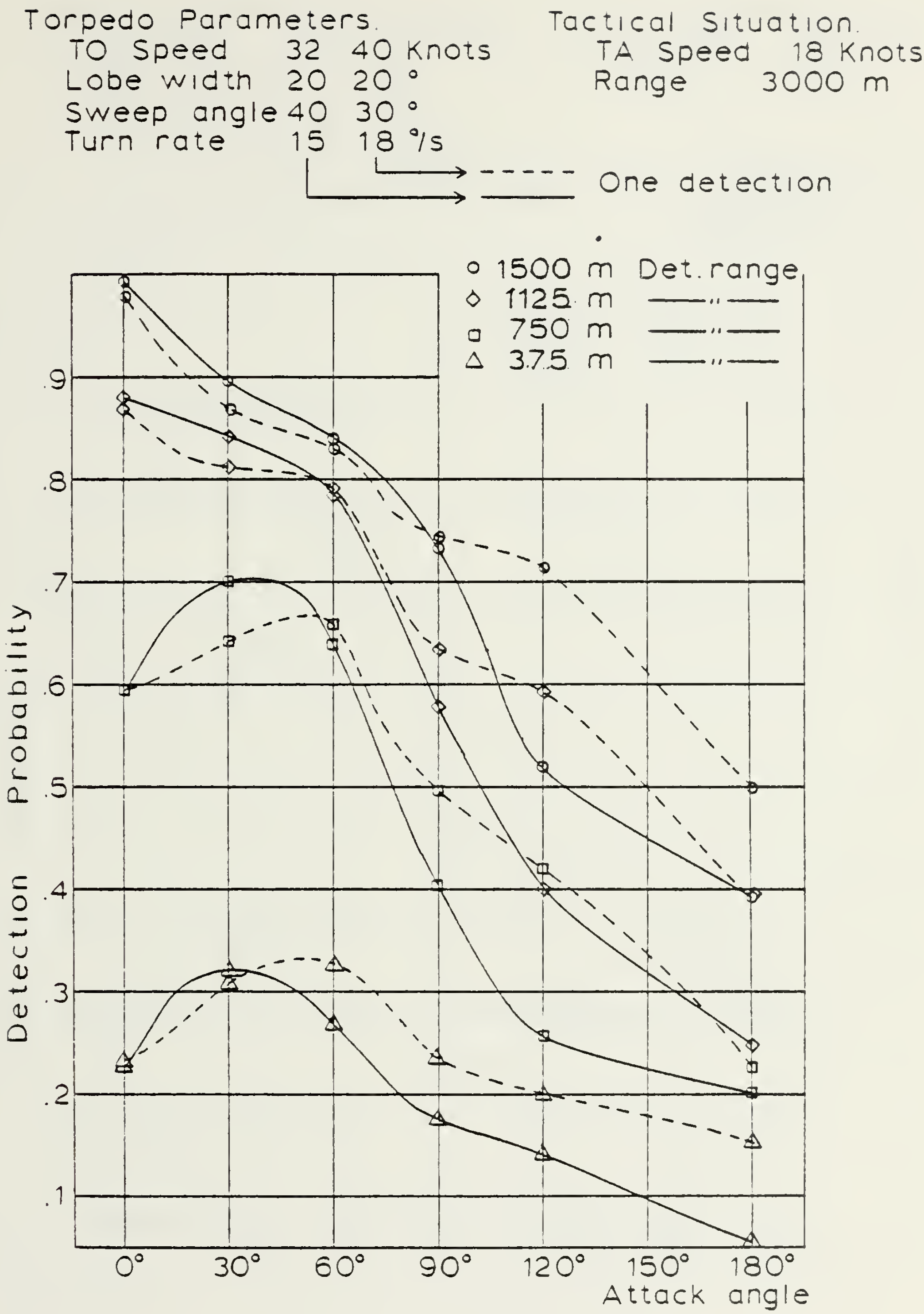


Figure 19 - COMPARISION OF TWO TORPEDOES WITH CHANGE IN DETECTION RANGE

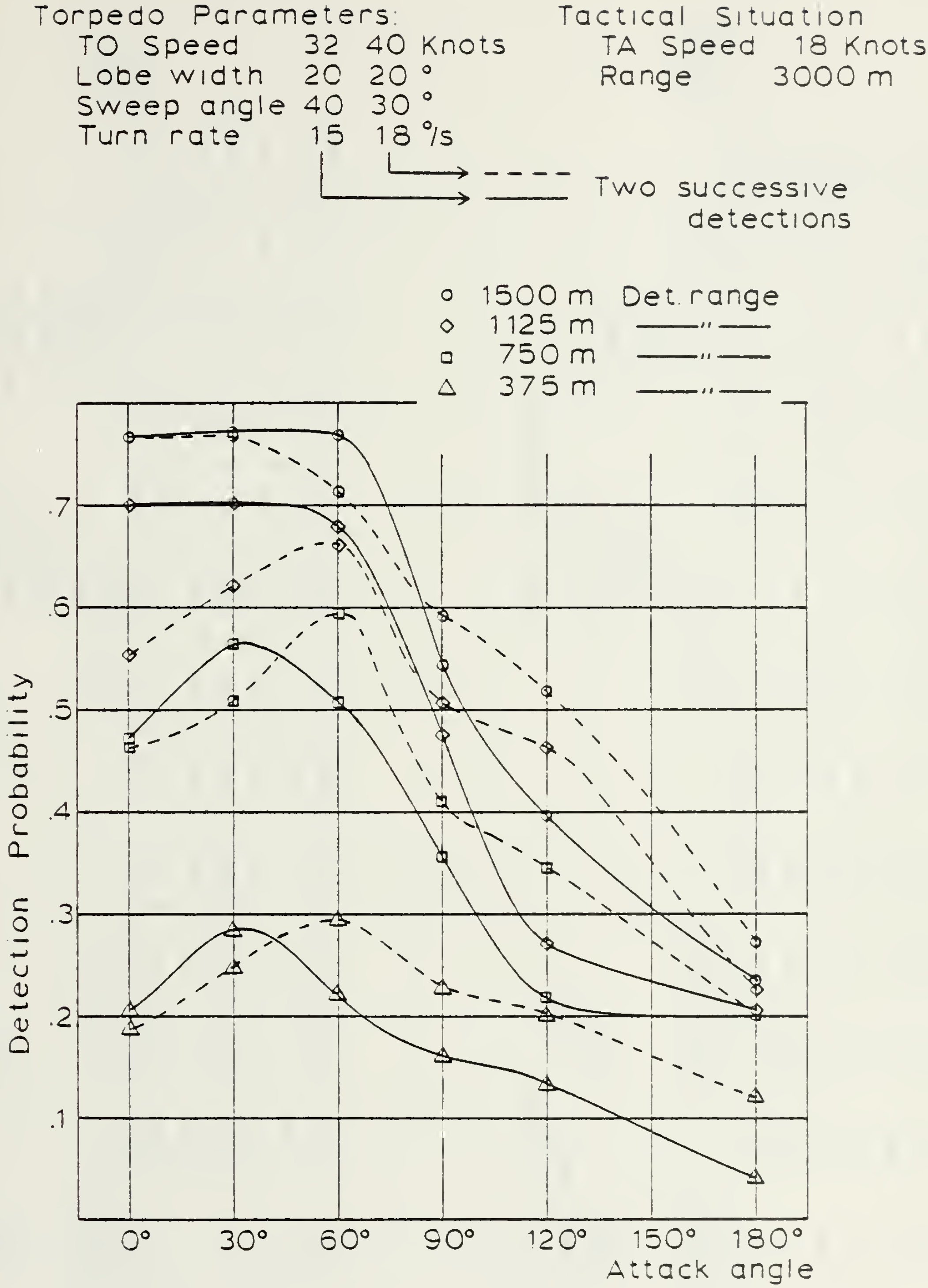


Figure 19.b. - COMPARISION OF TWO TORPEDOES
WITH CHANGE IN DETECTION RANGE

Tactical situation

Target speed 18 knots

Range 3000 m

Torpedo parameters

Torpedo speed 32 knots

Sweep angle 40 degrees

Lobe width 20 degrees

Turn rate 15 deg/sec

Attack angle	1 detection				2 detections				3 detections				Detection range m
	375	750	1125	1500	375	750	1125	1500	375	750	1125	1500	
0	.2267	.5933	.8800	.9933	.2067	.4733	.7000	.7667	.1667	.3600	.4800	.5333	
30	.3200	.7000	.8333	.8933	.2867	.5667	.7000	.7667	.2600	.3667	.5267	.5933	
60	.2667	.6067	.7867	.8400	.2200	.5067	.6800	.7667	.1933	.4267	.5600	.6067	
90	.1733	.4000	.5800	.7333	.1600	.3533	.4733	.5467	.1400	.2733	.3667	.3667	
120	.1400	.2533	.4000	.5133	.1333	.2133	.2667	.3933	.1200	.1733	.1867	.2333	
180	.0533	.2000	.2467	.3933	.0400	.2000	.2067	.2333	.0267	.1733	.1933	.2000	

Tactical situation

Target speed 18 knots

Range 3000 m

Torpedo parameters

Torpedo speed 40 knots

Sweep angle 30 degrees

Lobe width 20 degrees

Turn rate 18 deg/sec

Attack angle	1 detection				2 detections				3 detections				Detection range m
	375	750	1125	1500	375	750	1125	1500	375	750	1125	1500	
0	.2333	.5933	.8667	.9800	.1867	.4600	.5533	.7667	.1267	.2867	.3533	.4000	
30	.3067	.6400	.8133	.8667	.2467	.5067	.6200	.7667	.1933	.3733	.4133	.5400	
60	.3267	.6600	.7933	.8333	.2933	.5933	.6667	.7133	.2200	.4800	.5000	.6267	
90	.2333	.4933	.6333	.7400	.2267	.4067	.5067	.5933	.1733	.2933	.3133	.3867	
120	.2000	.4200	.5933	.7133	.2000	.3467	.4667	.5267	.1733	.2600	.3133	.3333	
180	.1533	.2267	.3867	.5000	.1200	.2000	.2267	.2733	.0867	.2000	.2000	.2200	

Table V - VARIATION IN DETECTION RANGE

H. COMBINED EFFECT OF LOBE WIDTH AND DETECTION RANGE

The following approximate relationships exist between lobe width, detection range and sonar power:

$$P = \frac{P_0 \cdot G_t \cdot \sigma \cdot G_r \cdot \lambda^2}{(4\pi)^3 \cdot R^4} \quad \text{Watts} \qquad (4.9)$$

where

$$G_t = G_r = (4 \cdot \pi / w) \qquad (6.1)$$

$$w = L^2$$

L = 2 x lobe width.

Ref [1;49].

w is defined as solid angle. The given equation is valid for small lobe width only. For larger lobe width the exact relationship is;

$$w = 2 \cdot \pi \cdot (1 - \cos l) \qquad (6.2)$$

l = lobe width.

The approximate relationship is close enough up to 60 degrees lobe width.

By substituting the approximate relationship into Eq. 4.9, we get a reduction of L^4 in receiving echo due to change in lobe width,

or

$$(L \cdot R)^4 = \text{constant}, \tag{6.3}$$

which combine range and lobe width, and implies that detection range is inverse proportional to lobe width for constant power transmitted.
It is therefore possible to plot this function for constant power transmitted, and use this as a prediction of hcw MOE may change with change in these two torpedo parameters (lobe width and detection range).
This is done in Fig. 20; and indicated by the dashed line going through 20 degrees lobe width and 750 m detetion range.

We then ran some simulation series in order to generate data points from the model. The data points gave the MOE , and by fitting curves we were able to get some indication of the relationship between the lobe width and the detection range as given by the model.

The application could be as follows;
For a given torpedo with lobe width 20 degrees and a detection range of 750 m, we ask the question, can MOE be increased without increasing power transmitted ?
The dashed curve through the point(20 degrees, 750 m) is a constant power curve, and by following the curve we observe how MOE is changing.
From the figure, it is obvious that a narrower lobe and a longer detection range gives a better result. But we also observe the assymptotical feature of the curves. We reach a point where the constant power curve and the constant MOE curve are parallel.

However, it should be born in mind that the theoretical relationship between lobe width and detection range is an approximation which does not account for absorption-effect or surface-effect. This implies that the constant power

curve in real life will be lowered. Only a more detailed analysis can say how much.

Tactical Situation
TA Speed 18 Knots
Range 3000 m

Torpedo Parameter
TO Speed 40 Knots
Sweep angle 30 °
Turn rate 18 °/s

One detection only

——— Constant detection probability
- - - - - - - Constant power transmitted

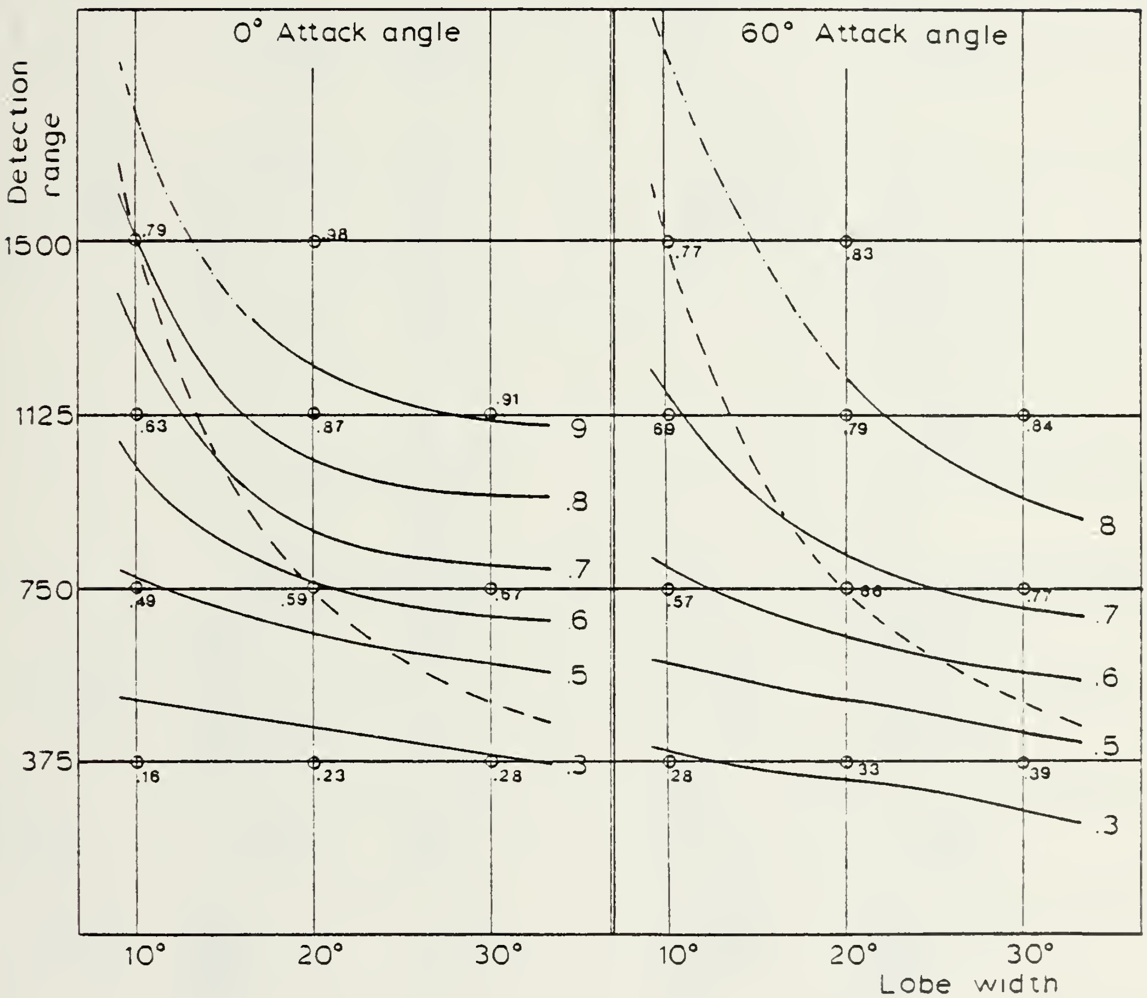


Figure 20 - VARIATION IN EFFECTIVENESS AS A FUNCTION OF LOBE WIDTH AND DETECTION RANGE

Tactical situation

Target speed 18 knots
Range 3000 m

Torpedo parameters

Torpedo speed 40 knots
Sweep angle 30 degrees
Turn rate 18 deg/s

Attack angle	1 detection				2 detections				3 detections				Detection range m
	375	750	1125	1500	375	750	1125	1500	375	750	1125	1500	
0°	.1600	.4933	.6267	.7867	.1267	.2467	.3600	.4600	.1200	.1133	.1800	.1600	10° lobe width
60°	.2800	.5667	.6933	.7733	.1667	.4467	.5400	.5533	.0867	.3067	.3667	.3667	
0°	.2333	.5933	.8667	.9800	.1867	.4600	.5533	.7667	.1267	.2867	.3533	.4000	20° lobe width
60°	.3267	.6600	.7933	.8333	.2933	.5933	.6667	.7133	.2200	.4800	.5000	.6267	

Tactical situation

Target speed 18 knots
Range 3000 m

Torpedo parameters

Torpedo speed 40 knots
Sweep angle 30 degrees
Turn rate 18 deg/s

Attack angle	1 detection				2 detections				3 detections				Detection range m
	375	750	1125	1500	375	750	1125	1500	375	750	1125	1500	
0°	.2800	.6667	.9133		.2333	.5533	.6733		.1867	.4200	.4867		30° lobe width
60°	.3867	.7200	.8400		.3733	.6400	.7333		.3333	.5467	.6067		

Table VI - VARIATION IN BOTH LOBE WIDTH AND DETECTION RANGE

I. EFFECT OF FIRING RANGE

The most important factor in achieving high detection probability is the difference between estimated target position and actual target position at the time when the torpedo is in position to detect. The effect on the detection probability is mainly due to the time the torpedo takes to reach within detection range of target and the speed/course errors in target data.

As we increased the firing range, we experienced as anticipated a degradation in MOE. This degradation was experienced for both the 32 and the 40 knots torpedo.
The variation in firing ranges were at the following values: 1500 - 3000 - 5000 - 7000 meters.
Fig. 21.a. and b. shows consistently the importance of short firing ranges. This applies to both one detection and two successive detections.
Fig. 22.a. and b. shows an additional advantage with short firing ranges; a considerable improvement at firing with small aspect (attack angle), less than 30 degrees. Again this applies for both types of torpedoes.
Also, we get an indication that at short ranges, about 1500 meters, there is no significant difference in MOE of the two types of torpedoes up to an attack angle of 90 degrees.

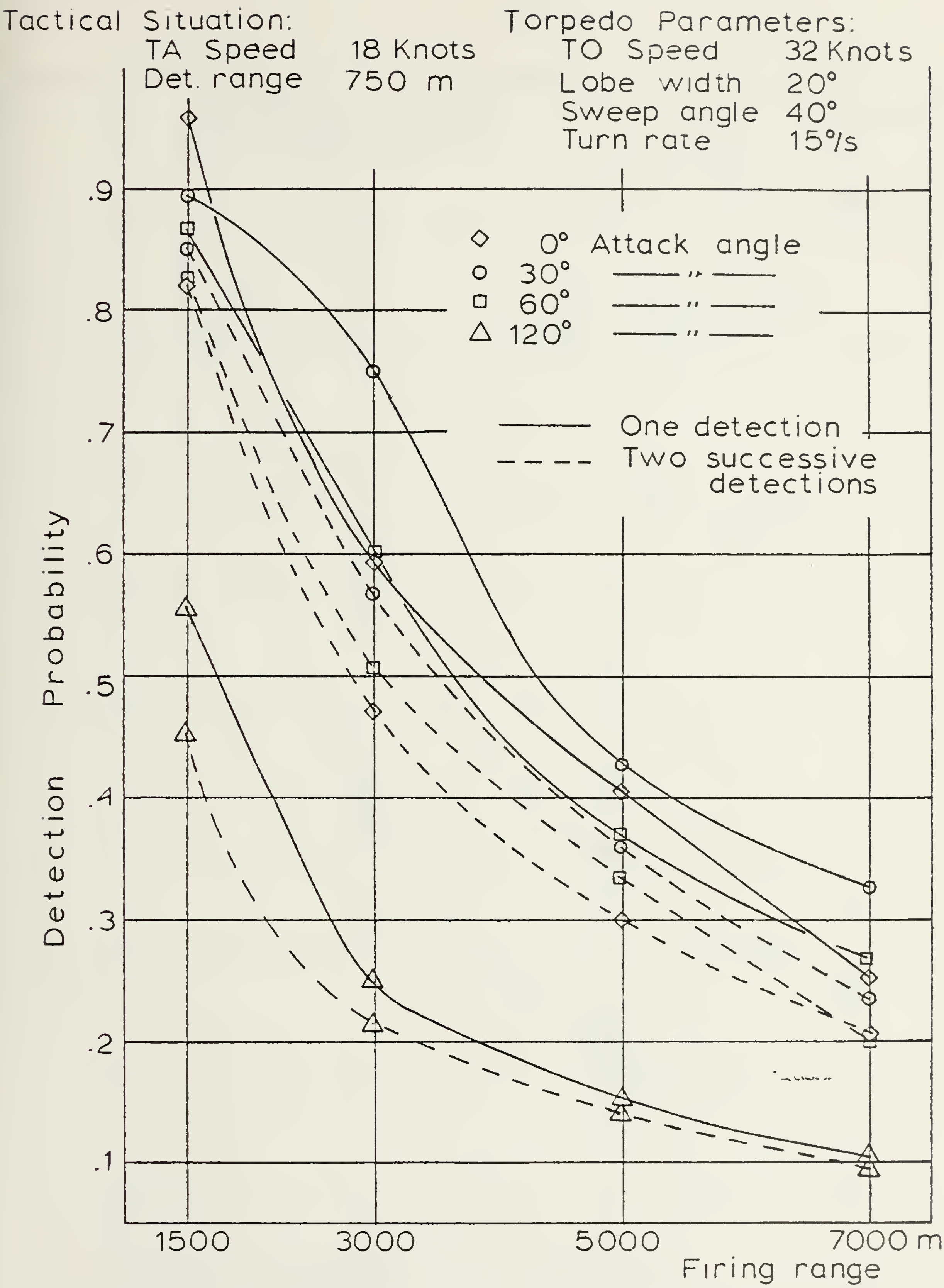


Figure 21 - EFFECT OF FIRING RANGE

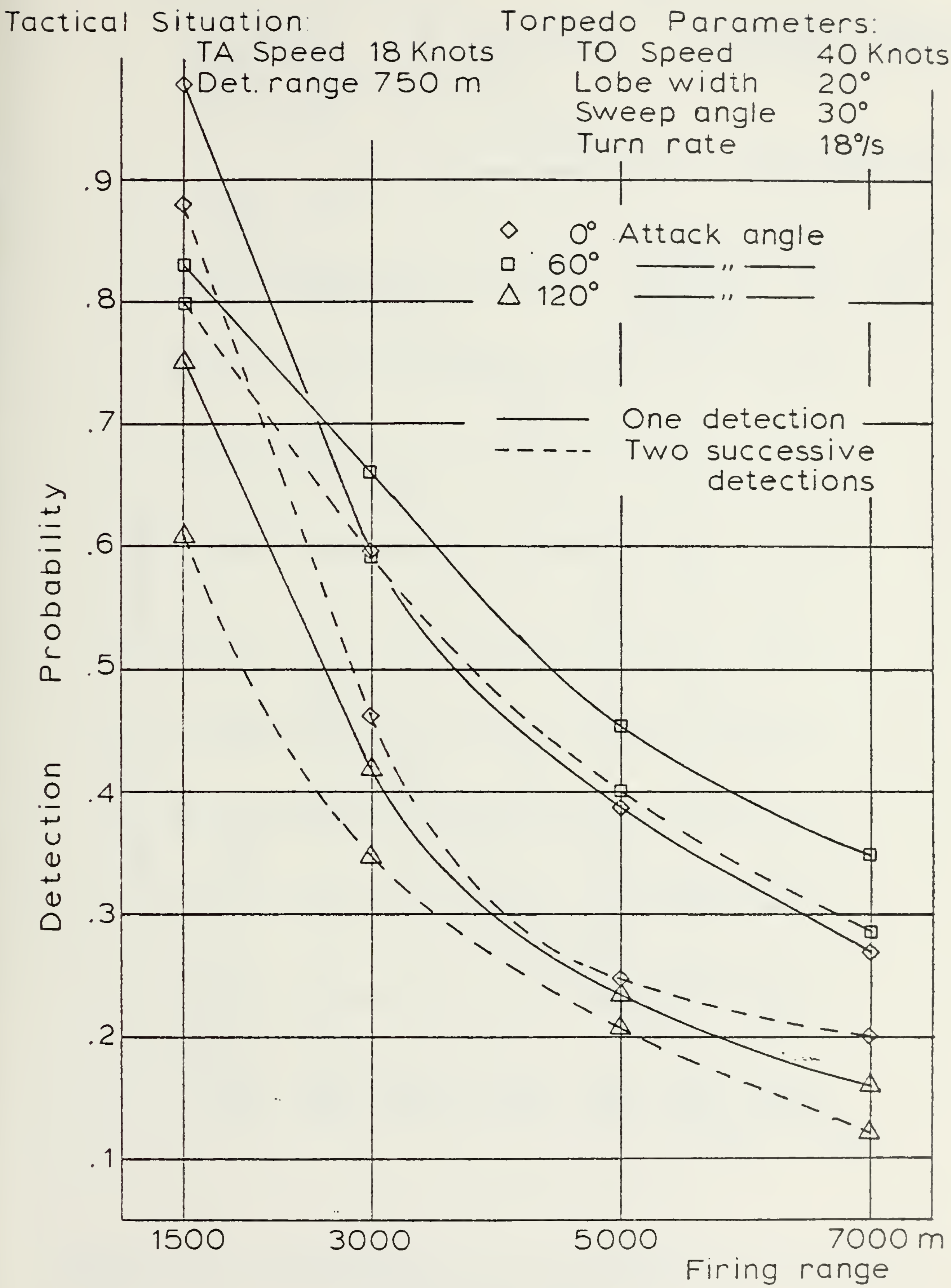


Figure 21.b. - EFFECT OF FIRING RANGE

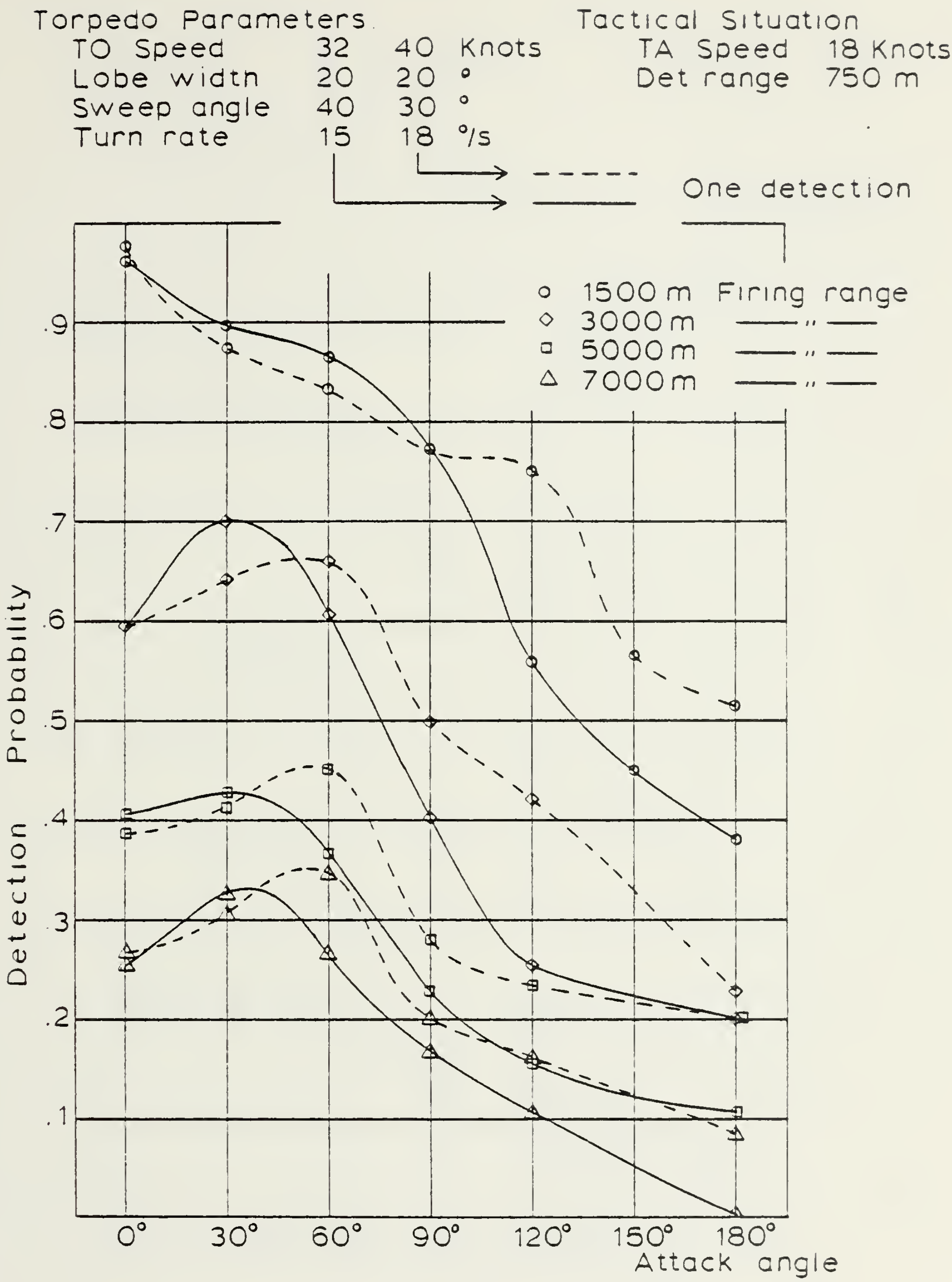


Figure 22 - COMPARISION OF TWO TORPEDOES WITH CHANGE IN FIRING RANGE

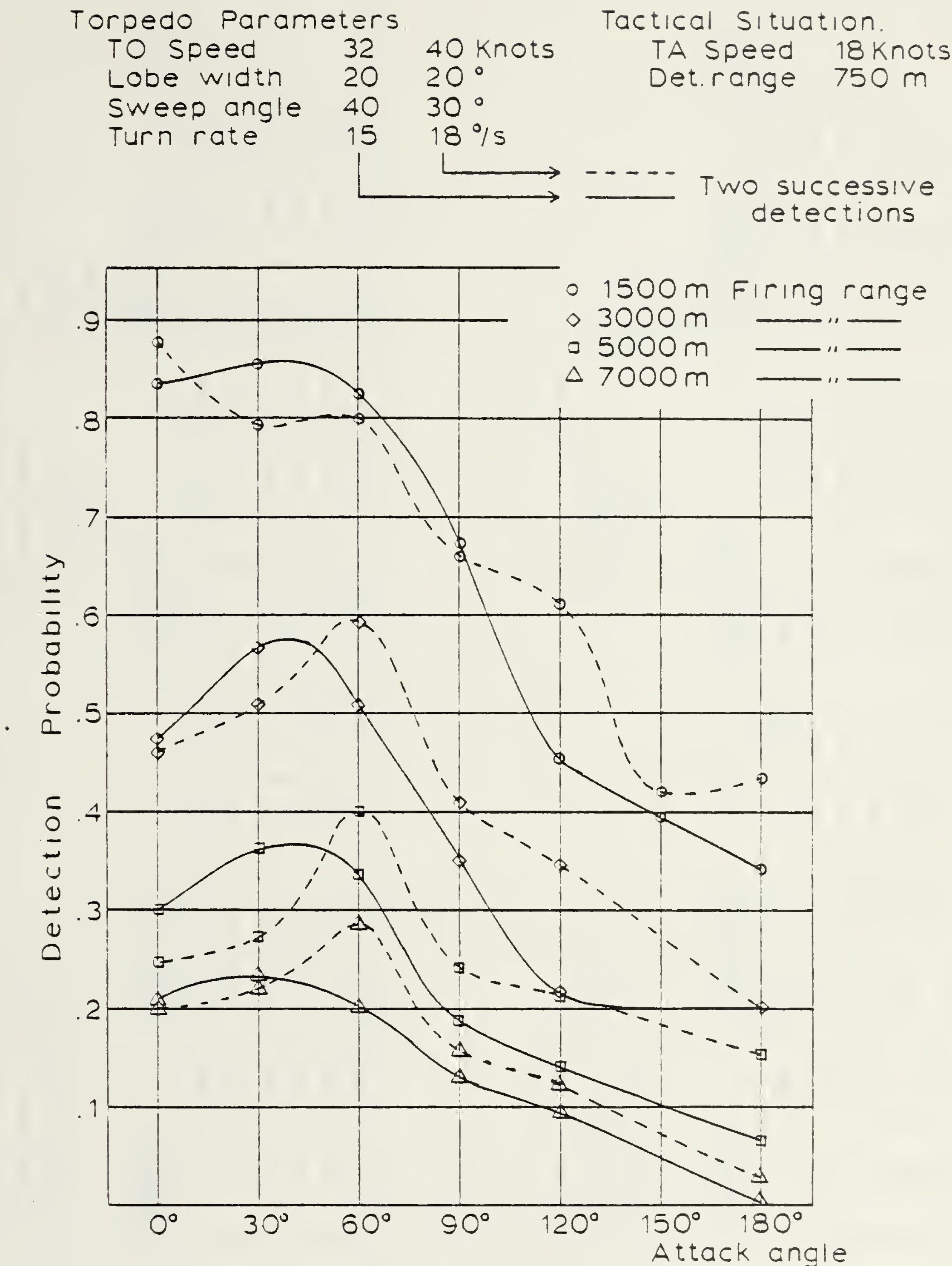


Figure 22.b. - COMPARISION OF TWO TORPEDOES WITH CHANGE IN FIRING RANGE

Tactical situation

Target speed 18 knots

Detection range 750 m

Torpedo parameters

Torpedo speed 32 knots

Sweep angle 40 degrees

Lobe width 20 degrees

Turn rate 15 deg/sec

Attack angle	1 detection				2 detections				3 detections				Range m
	1500	3000	5000	7000	1500	3000	5000	7000	1500	3000	5000	7000	
0	.9600	.5933	.4067	.2533	.8333	.4733	.3000	.2067	.5600	.3600	.1733	.1000	
30	.8933	.7000	.4267	.3267	.8533	.5667	.3600	.2333	.7533	.3667	.2533	.1800	
60	.8667	.6067	.3667	.2667	.8267	.5067	.3333	.2000	.7267	.4267	.2400	.1867	
90	.7733	.4000	.2267	.1667	.6733	.3533	.1867	.1267	.5333	.2730	.1600	.1200	
120	.5600	.2533	.1533	.1067	.4533	.2133	.1400	.0933	.3467	.1733	.0867	.0533	
180	.3800	.2000	.1067	.0000	.3400	.2000	.0667	.0000	.2667	.1733	.0133	.0000	

Tactical situation

Target speed 18 knots

Detection range 750 m

Torpedo parameters

Torpedo speed 40 knots

Sweep angle 30 degrees

Lobe width 20 degrees

Turn rate 18 deg/sec

Attack angle	1 detection				2 detections				3 detections				Range m
	1500	3000	5000	7000	1500	3000	5000	7000	1500	3000	5000	7000	
0	.9800	.5933	.3867	.2667	.8800	.4600	.2467	.2000	.5200	.2867	.1933	.1533	
30	.8733	.6400	.4133	.3067	.7933	.5067	.2733	.2200	.6800	.3733	.2000	.1600	
60	.8333	.6600	.4533	.3467	.8000	.5933	.4000	.2867	.7333	.4800	.3133	.2000	
90	.7667	.4933	.2800	.2000	.6600	.4067	.2400	.1533	.6000	.2933	.1933	.1333	
120	.7533	.4200	.2333	.1600	.6133	.3467	.2067	.1200	.5000	.2600	.1467	.1000	
180	.5133	.2267	.2000	.0867	.4333	.2000	.1533	.0267	.2867	.2000	.0467	.0000	

Table VII - VARIATION IN FIRING RANGE

J. EFFECT OF TARGET SPEED

Generally, we anticipated a degradation in MOE as the target speed was increased. And overall, this was confirmed.
The simulations were carried through at 12, 18, 24, 30 knots target speed.

However, fig. 23.a and b shows some interesting patterns regarding optimal attack angle for different target speeds. For a 32 knots torpedo, at 60 degrees attack angle, the torpedo is equally good for any type of target speed for one detection only. For two successive detections, the torpedo is equally good between 30 and 90 degrees for 12 and 18 knots target. A 24 knots target gives a consistently lower MOE over the whole range of attack angles, and the 2 simulation runs with a 30 knots target confirmed that trend for the 32 knots torpedo.

We may form the conclusion that for one detection only 60 degrees attack angle is an optimal attack angle for the range of target speeds. For two successive detections, 30 to 90 degrees attack angle gives equally good MOE between target speed of 12 and 18 knots.

One interesting point is that it seems that if the target speed is less than 0.4 of the torpedo speed the optimal attack angle shifts forward to 0 degree.
This also applies to two successive detections.

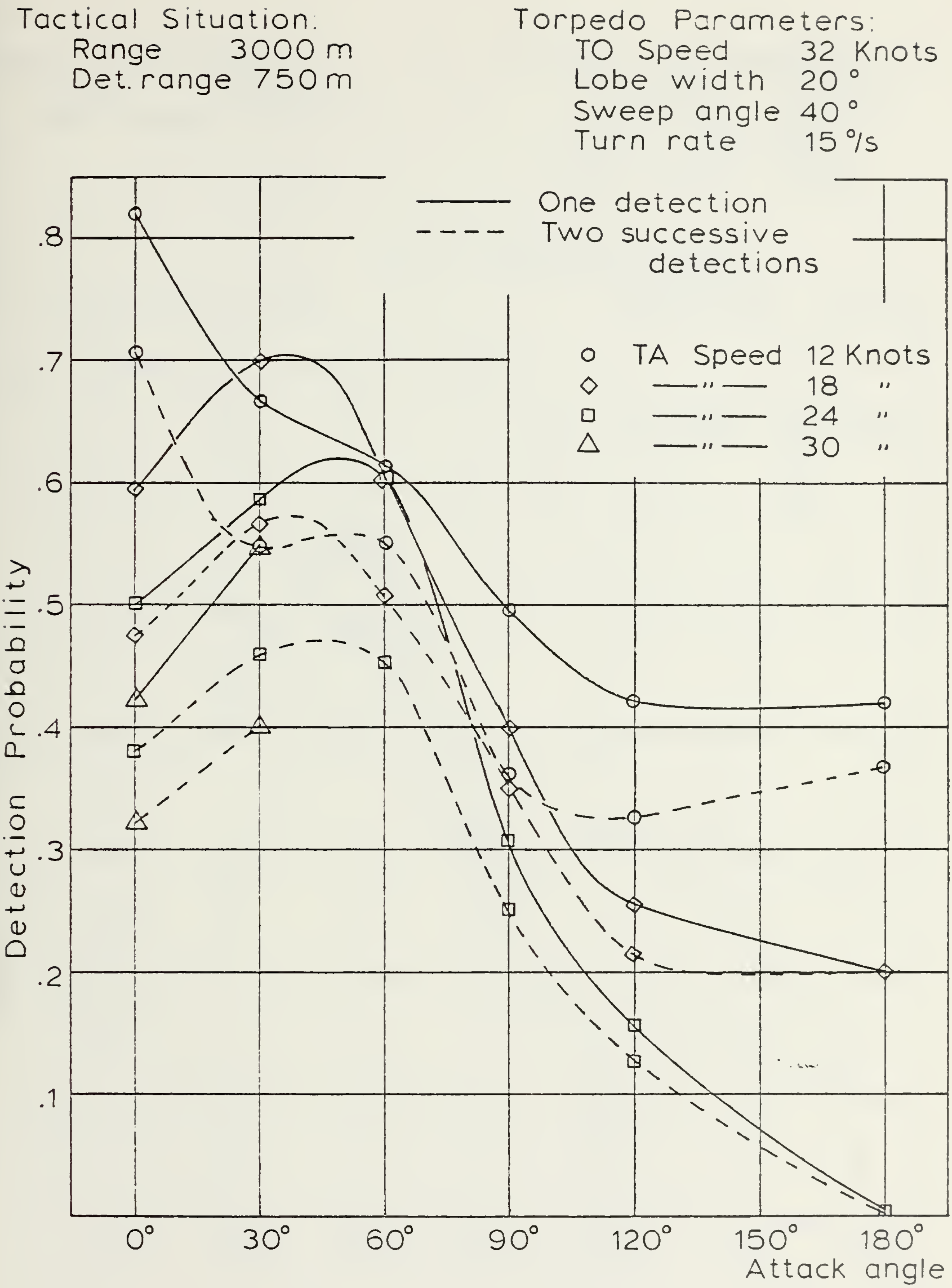


Figure 23 - EFFECT OF TARGET SPEED

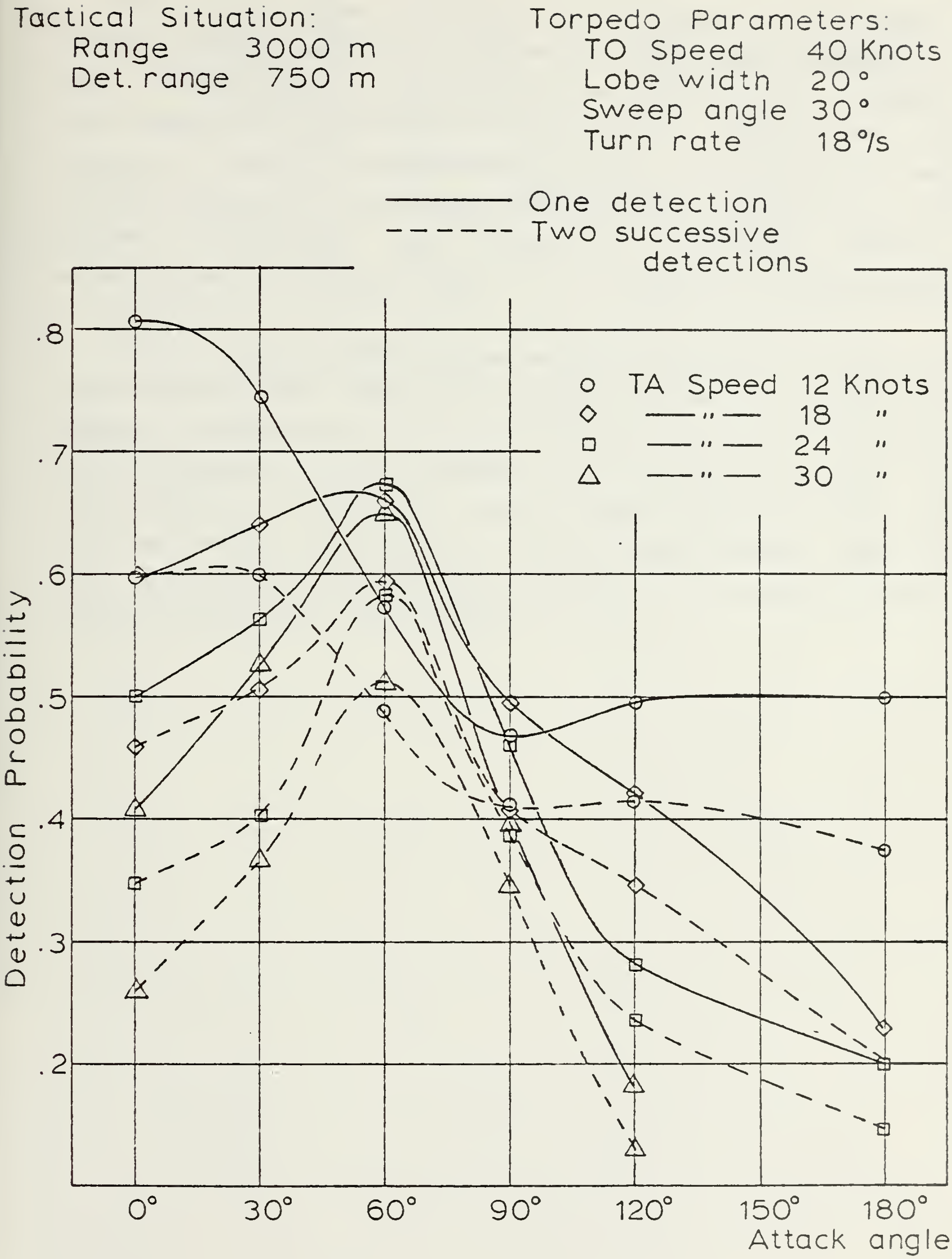


Figure 23.b. - EFFECT OF TARGET SPEED

For a 40 knot torpedo, in addition to the point of optimal attack angle at 0 degree for slow target speeds, we also experienced a relatively low MOE for slow targets in the range 45 to 105 degrees attack angle, compared to fast targets. But as a compensation, MOE is increased for small attack angles and the astern attack angle compared to fast target. Obviously, some type of a breaking point is experienced for target speed of .4 or less of torpedo speed.

Why a slow target produces this increase in MOE in the two extreme cases (ahead and astern) may be explained by the balance between time to reach detection range and the total relative speed. It is, however, more difficult to give any explanation of why a slow target should produce a lower MOE for some attack angles than a faster target does. One would have anticipated an increase in MOE over the whole range of attack angles for a slow target.

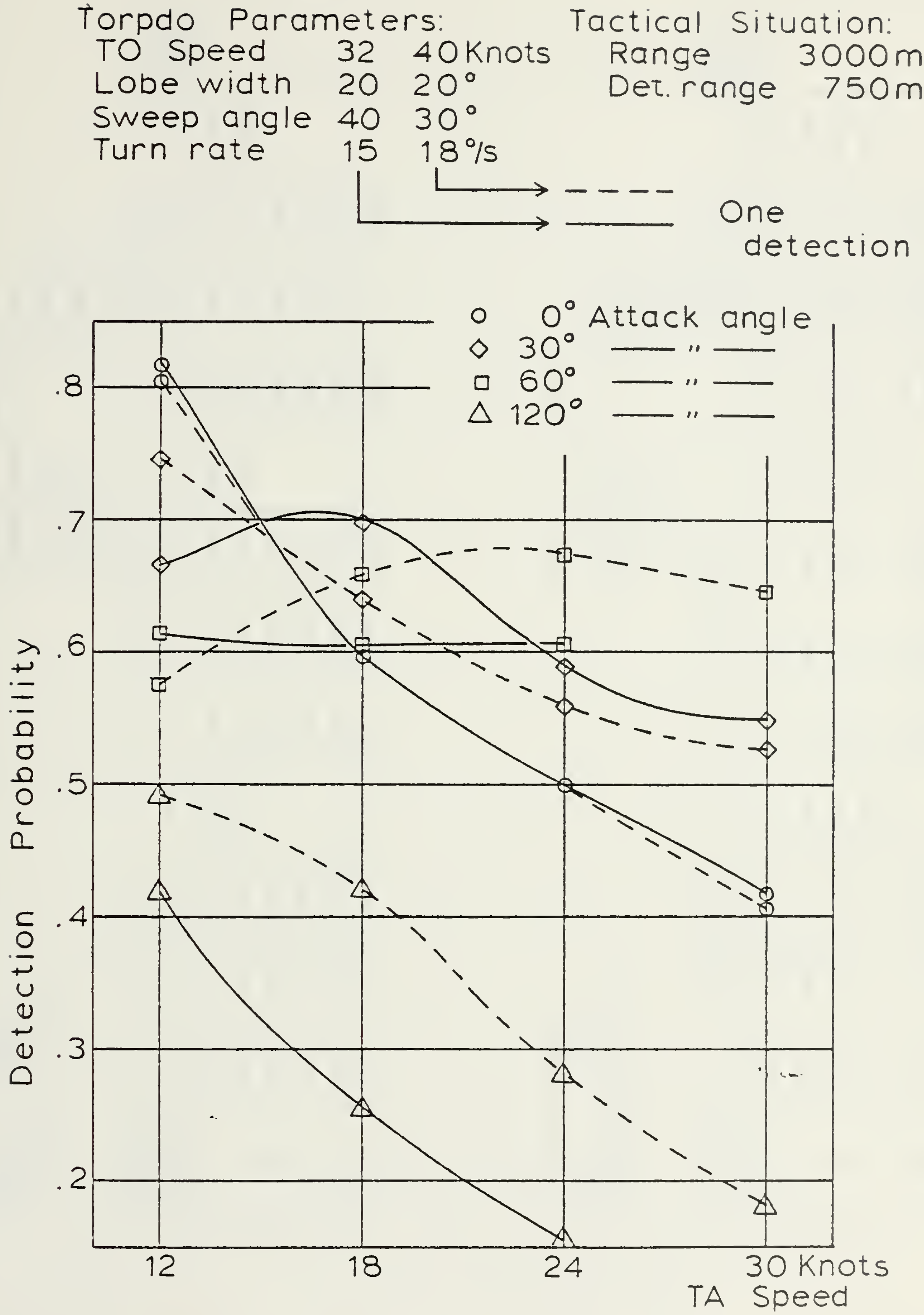


Figure 24 - COMPARISION OF TWO TORPEDOES WITH CHANGE IN TARGET SPEED

Tactical situation

Range 3000 m

Detection range 750 m

Torpedo parameters

Torpedo speed 32 knots

Sweep angle 40 degrees

Lobe width 20 degrees

Turn rate 15 deg/sec

Attack angle	1 detection 12	18	24	30	2 detections 12	18	24	30	3 detections 12	18	24	30	Target speed knots
0	.8200	.5933	.5000	.4200	.7067	.4733	.3800	.3200	.4667	.3600	.2533	.1867	
30	.6667	.7000	.5867	.5467	.5467	.5667	.4600	.4000	.4200	.3667	.3267	.2867	
60	.6133	.6067	.6067		.5533	.5067	.4533		.3933	.4267	.3667		
90	.4933	.4000	.3067		.3600	.3533	.2467		.3133	.2730	.2133		
120	.4200	.2533	.1533		.3267	.2133	.1267		.2400	.1733	.1067		
180	.4200	.2000	.0000		.3667	.2000	.0000		.2667	.1733	.0000		

Tactical situation

Range 3000 m

Detection range 750 m

Torpedo parameters

Torpedo speed 40 knots

Sweep angle 30 degrees

Lobe width 20 degrees

Turn rate 18 deg/sec

Attack angle	1 detection 12	18	24	30	2 detections 12	18	24	30	3 detections 12	18	24	30	Target speed knots
0	.8067	.5933	.5000	.4067	.6000	.4600	.3467	.2600	.4133	.2867	.1933	.1400	
30	.7467	.6400	.5600	.5267	.6000	.5067	.4000	.3667	.4267	.3733	.3267	.3267	
60	.5733	.6600	.6733	.6467	.4867	.5933	.5867	.5133	.3600	.4800	.5333	.4267	
90	.4667	.4933	.4600	.4067	.4067	.4067	.3867	.3400	.3200	.2933	.3333	.2667	
120	.4933	.4200	.2800	.1800	.4133	.3467	.2333	.1267	.2333	.2600	.1867	.1000	
180	.5000	.2267	.2000		.3733	.2000	.1467		.2467	.2000	.0067		

Table VIII - VARIATION IN TARGET SPEED

VII. TACTICAL ANALYSIS

In addition to the detailed parametric analysis, which has been shown previously, we also could expand the analysis to cover more tactical related problems. If we assume a given target speed, we could construct detection probability charts as shown in Fig. 25. a. and b.

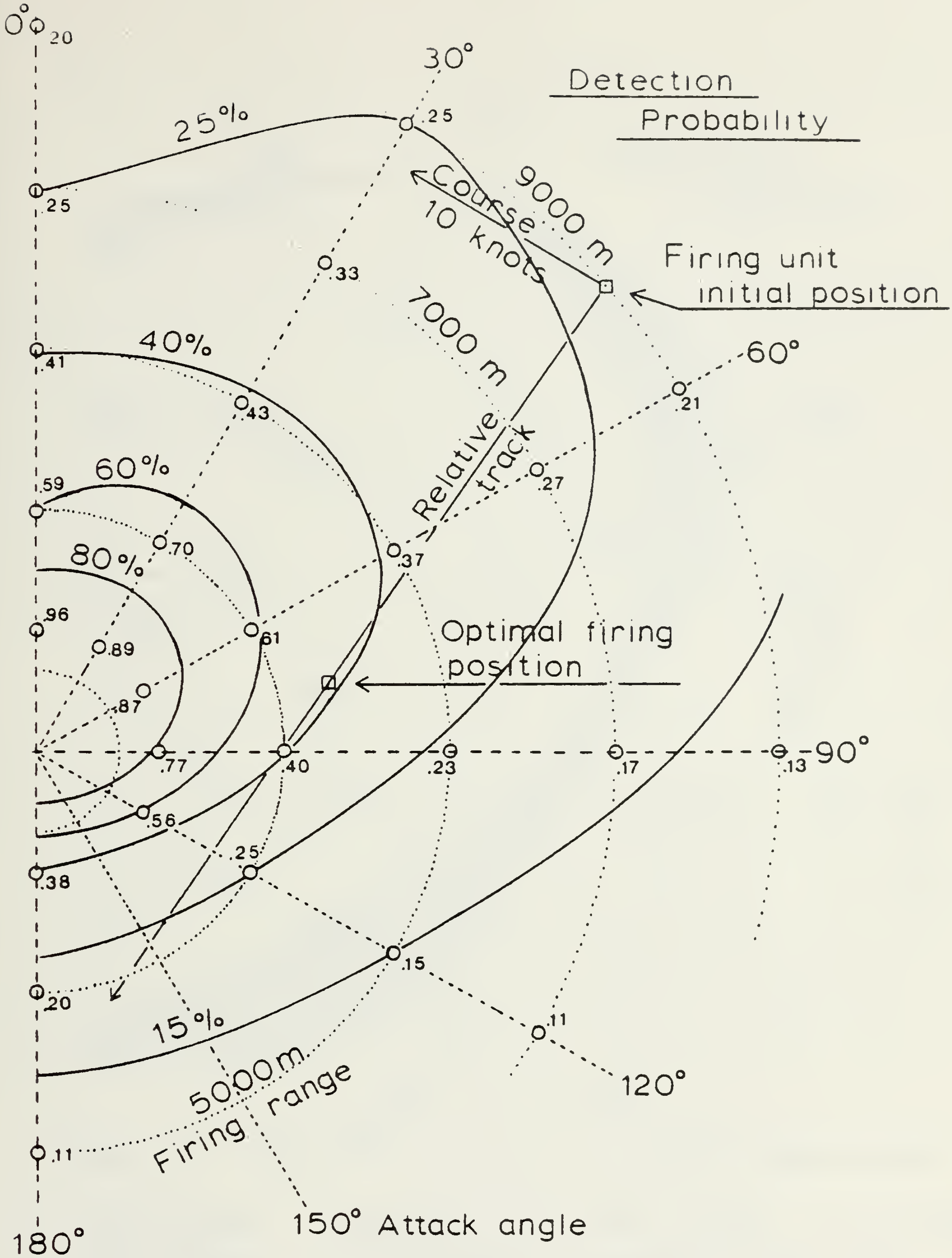
This analysis would then naturally fall into two areas:

- direct comparison of two or more different types of torpedoes.
- effect of tactical situation on the detection probability.

The two charts (Figs. 25.a. and b.) were formed by running simulation runs for differnt tactical situations (range and attack angle), and then fitting constant detection probability curves through the data points.

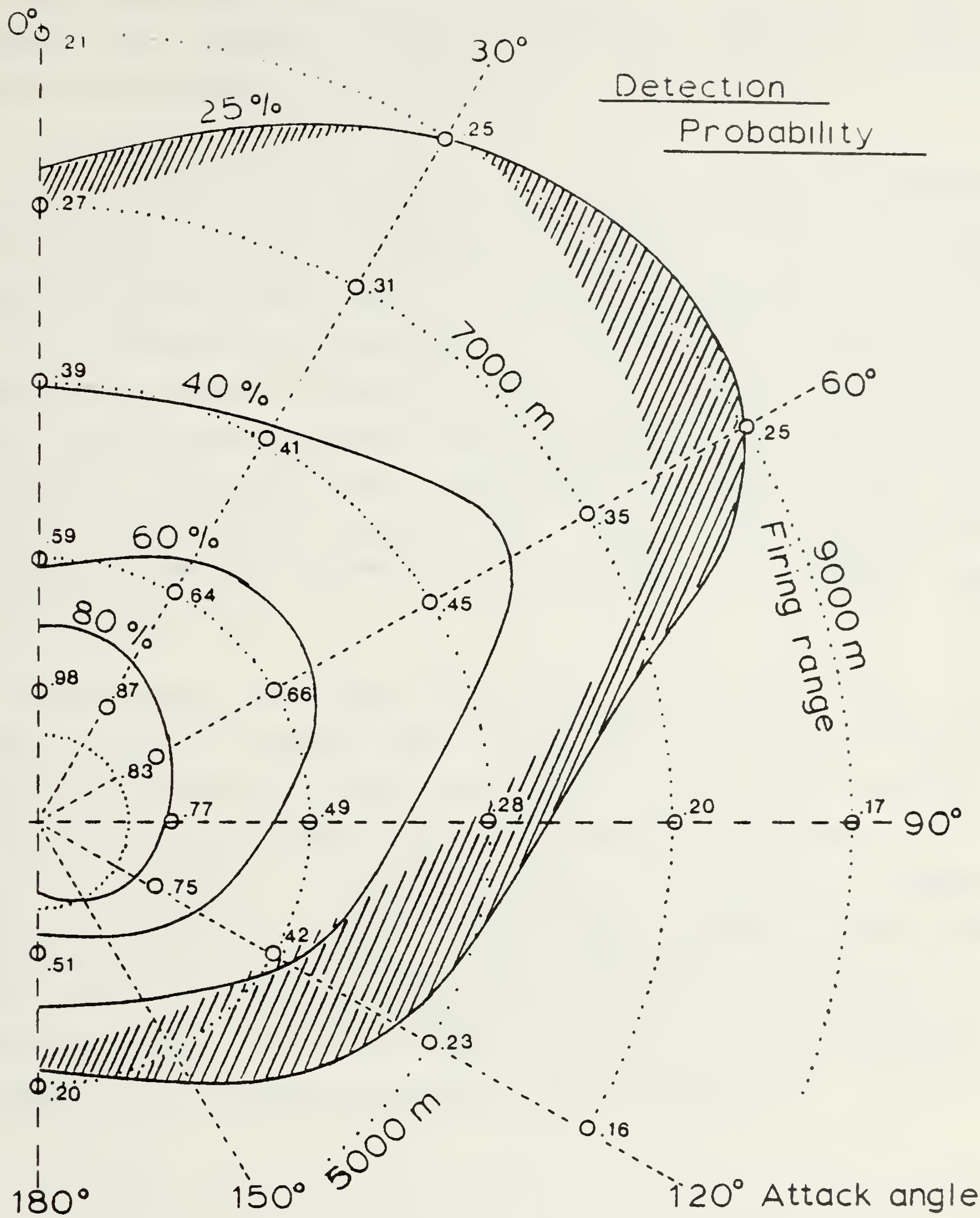
The use of these types of charts falls into two areas: Evaluate different torpedo types for different tactical situations; essentially, which torpedo is best. Or for a given tactical situation, how could the situation be improved, and what options exist.

The first type of use applies mainly to operational planning; operational requirement in the design phase of a torpedo and procurement. By laying one chart atop of the other; we get a visual picture of how much is improved when using a 'better' torpedo, and for which tactical situation. The shaded area in Fig. 25.b. shows how many more tactical situations have been covered when going from a 32 knots torpedo to a 40 knots torpedo for 0.25 detection probability.



Det. range	750 m	TO Speed	32 Knots
TA Speed	18 Knots	Sweep angle	40°
Turn rate	15 °/s	Lobe width	20°

Figure 25 - EXAMPLE OF TACTICAL GUIDELINES



Det. range	750 m	TO Speed	40 Knots
TA Speed	18 Knots	Sweep angle	30 °
		Lobe width	20 °
		Turn rate	18 °/s

Figure 25.b. - EXAMPLE OF TACTICAL GUIDELINES

The other type of use of the charts is tactical. When a firing unit decides to attack, and finds itself in a given tactical situation, the question is: What to do ?

For given target speed and own max speed, the charts make it possible in a simple way to decide where to go and what course to keep. Also from the charts, one can decide where on the relative course is the optimal firing position. For a submarine attacking a zig-zagging target, the Commanding Officer can better make his evaluation of when to fire, as the attack angle and the distance are continuously changing. He can see what improvement to expect when the target will change course next time. An example of a tactical situation and the course of action to follow are given in Fig. 25.a.

These points also bring up the question of what to improve in the operational picture; the firing unit's ability to acheive a good firing position or the torpedo's ability to detect target from non-optimal situations.
In this discussion, the guided torpedo has to be brought into the picture. The effectiveness of guidance has not been adressed at all in this study, basically because that would have significantly expanded the scope of the study, as well as bringing in the whole problem of fire control equipment, its effectiveness and its reliability.

VIII. CONCLUSIONS

The study was carried out in order to investigate the detection process of an active sonar homing torpedo used against surface ships.

Specifically, we wanted to study the effect of changes in torpedo parameters such as torpedo speed, turn rate, sweep angle and detection range, as well as changes in the tactical situation such as target speed, firing range and attack angle.

In an attempt to gain insight into the complexity of a homing torpedo, the described model was built and the simulations done as previously shown.

In designing a homing torpedo and evaluating torpedo tactics the detection probability is an essential part of the total effectiveness of the torpedo.
To be able to hit the target, the torpedo has first to detect it, which justifies why we started out with analyzing the detection process.

Also, as part of this analysis we investigated certain aspect of the next step in the operational process; acquisition.
It is not difficult to visualize tests which may be used in order to recognize an echo as a detection and subsequently a target to attack. Some of these tests may be doppler, successive detections, detections within a given range, 2-of-3 detections, size of echo, length of echo etc.
The problem of false echo, however, was not approached in

this study. That would have to be the next to consider in relation to reducing the number of successive detections in order to acquire a target.

In order to allow for the errors in tracking of the target before firing and also small maneuvering of the target after firing, we introduced errors in the target speed and course when calculation of the torpedo main firing course was done.

During runs the torpedo was unguided, and did not react on any detection; i.e. it did not attack the target. For sonar condition, isovelocity was assumed and no surface effect was built into the model.

The result gave certain insight into the complexity of the detection process, stressing the importance of a good tactical firing position, and of a high speed torpedo with long detection range.

However, the data also showed the relationship between detection range, lobe width and turn rate, as well as weighting the sweep angle in relation to torpedo speed. It can also be concluded from the results that changes in torpedo parameters as turn rate and sweep angle, which may be inexpensive modifications, will not give a significant improvement.

Generally, the overall important factor was the time the torpedo used in order to travel within the detection range of the target. This was due primarily to the error generated in the target data, obviously the actual value of the result is sensitive to these assumptions.
However, the understanding and insight in the detection process achieved by simulation should not be reduced by other assumptions with regard to error in target data.

With regard to the analysis, the result has shown a consistent and general trend that if we are able to require only one detection for acquiring a target, the detection probability is significantly higher than if more than one detection is required. And what is more important, the potential for improving/optimizing a homing torpedo is also significantly higher for one detection only.
This implies a large payoff for other methods of keeping down the probability of false detections.

Secondly, a high speed torpedo has shown a general superiority in MOE. This was specially obvious in attack angles greater than 90 degrees, which tends to make a high speed torpedo more of an all-round/reliable torpedo with regard to tactical situations.

Thirdly, except for changes in attack angle and firing range, the detection range seems to influence the MOE strongly.

These three remarks all point towards an improvement in the sonar-/filtering-area as the most promising area in which to carry out research and invest effort.

This study has also pointed out the advantage of high torpedo speed and firing at short ranges. There exists therefore considerable argument for a short range, high speed torpedo, given that one is able to position the torpedo at a short firing range; i.e. a small, simple torpedo.

Basically, there are two schools of thought;

- a highly sophisticated torpedo; long range, guidance, expensive, but close to the one shot-one hit idea.
- a simple, high speed torpedo; short range,

non-guidance, inexpensive, and requiring either a firing unit which can get into an optimal firing position or a larger number of shots to acheive hit.

The result may be useful in giving example of how tactical guidelines can be evaluated by the simulation approach. But more significant is pointing out the importance of torpedo capability and the tactical situation. Obviously, we have to look on the whole torpedo system, including the firing unit. Investment in resources and effort should not necessarily be spent only on the torpedo in order to increase its effectiveness, but may be spent on the firing unit as well in order to make the unit able to reach a better firing position.

A follow-on of this study may be to investigate the attack process of the torpedo, including the acquisition- and hit-problem.
Then the question of guidance during torpedo run should be analyzed in order to better evaluate the problem of choosing between a few sophisticated, expensive, guided torpedo system or many simple, inexpensive, nonguided torpedo systems.

APPENDIX A

PRINT OUT OF SIMULATION PROGRAM

```
C     A TORPEDO SIMULATION.
C     SIMULATING AN ACTIVE HOMING TORPEDO DURING SEARCH.
C     THE PROGRAM IS RUN IN 0.5 SEC STEPS.
      COMMON ISEED2, TTIME, TC, TA, TRATE, RANGE, ALFA, LAMBD, TADEC,
     *BEAR, RAD, TAC, CCOR, DEVSP, BNG, FN, PH2, MCOURS, TCOURS,
     *MXT, MXM, IK, IDTIME, ITIME, XT, YT, XTAR, YTAR, TDIST, MDIST,
     *TURNTC, INTVAL, PHI, RMAX(5,6),IRANGE, DIST,IPRINT
      COMMON/DATA/DA,DFLOB
      COMMON/TARGET/TACMG,TAMI,RNGMOD,DA1,COUR,CE(10),SE(15),JRUN,
     *IFLAG,DA2
      DIMENSION RM(5,5), VAR(5), DET(150,5), DETB(150,5),STD(5),
     *ASPEC(150,5),DERB(150,5),CLOSB(150,5),KON(150,5)
      REAL LAMBD, MCOURS, MXT, MXM, MDIST, LAMBDD
      INTEGER RUNOUT

C     SETTING OF CONSTANTS (STEP 1)
      CALL OVFLOW
      PHI=3.141592654
      PH2=2.*PHI
      RAD=PH2/360.
      ISEED1=362716
      ISEED2=961695
C     DCOREC  -  MAX ERROR IN TARGET COURSE ESTIMATE
      DCOREC=15.
      DCOR=DCOREC*RAD
C     DSPEED  -  ST DEV IN TARGET SPEED ESTIMATE
      DSPEED=3.
      DEVSP=DSPEED*0.5
      IDTIME=1
C
C     SET NUMBER OF ITERATIONS
      IRUN=150
C
C     SET PRINT OUT MODE
      IPRINT=1
C
C     SET LOBE OFF TORPEDO CENTER BEARING
      DFLOB=0.
C
C     SET TABLES TO ZERO (STEP 2)
      DO 11 I=1,5
      DO 12 J=1,5
      RM(I,J)=0.
   12 CONTINUE
   11 CONTINUE
      DO 13 J=1,5
      DO 14 I=1,IRUN
      KON(I,J)=0
```

```
 14   CONTINUE                                                   TOR00490
 13   CONTINUE                                                   TOR00500
      DA2=0.                                                     TOR00510
C                                                                TOR00520
C     COMPUTE TARGET ERRORS AND STORE                            TOR00530
      DO 20 I=1,10                                               TOR00540
      CE(I)=-(15.*RAD+CCOR/10.)+(CCOR/10.)*I*2.                  TOR00550
 20   CONTINUE                                                   TOR00560
      SE(1)=-1.8737*DEVSP                                        TOR00570
      SE(2)=-1.2825*DEVSP                                        TOR00580
      SE(3)=-0.968*DEVSP                                         TOR00590
      SE(4)=-0.7285*DEVSP                                        TOR00600
      SE(5)=-0.525*DEVSP                                         TOR00610
      SE(6)=-0.34*DEVSP                                          TOR00620
      SE(7)=-0.1675*DEVSP                                        TOR00630
      SE(8)=0*DEVSP                                              TOR00640
      SE(9)=0.1675*DEVSP                                         TOR00650
      SE(10)=0.34*DEVSP                                          TOR00660
      SE(11)=0.525*DEVSP                                         TOR00670
      SE(12)=0.7285*DEVSP                                        TOR00680
      SE(13)=0.968*DEVSP                                         TOR00690
      SE(14)=1.2825*DEVSP                                        TOR00700
      SE(15)=1.8737*DEVSP                                        TOR00710
C                                                                TOR00720
C                                                                TOR00730
 100  DO 900 JRUN=1,IRUN                                         TOR00740
C     SET RUN COUNTERS (STEP 3)                                  TOR00750
C                                                                TOR00760
C     IFLAG=1; TOO LOW TORPEDO SPEED                             TOR00770
      IFLAG=0                                                    TOR00780
      ICONT=0                                                    TOR00790
      JCONT=0                                                    TOR00800
      ITIME=0                                                    TOR00810
      IL=0                                                       TOR00820
      IM=0                                                       TOR00830
      DIST=0.                                                    TOR00840
      MXT=0.                                                     TOR00850
      MXM=0.                                                     TOR00860
      RUNCUT=0                                                   TOR00870
C                                                                TOR00880
C     READ IN SETTING(TORP AND TACTICAL)                         TOR00890
C     FIRST RUN ? (STEP 4)                                       TOR00900
      IF(JRUN .GT. 1)GO TO 160                                   TOR00910
      CALL PARMET                                                TOR00920
C                                                                TOR00930
      WRITE(6,228)OFLOB                                          TOR00940
 228  FORMAT(1X,/,1X,'SONAR MAIN LOBE OFF-SET FROM CENTER ',     TOR00950
     *'BEARING',F6.2,' TIMES DEFLECTION ANGLE',/)                TOR00960
```

```
      TDIST=TD/2.
      MDIST=TA/2.
      TURNTD=TRATE/2.
      INTVAL=IFIX((TTIME/0.5)+0.5)
C     INTVAL GIVES NUMBER OF TIMESTEPS FOR EACH TRANSMISSION
C
      IF(IPRINT .EQ. 0)GO TO 160
C
C     PRINT OF HEADING
 151  WRITE(6,230)
 230  FORMAT(1X,//,1X,'RUN',4X,'EST OF TARGET',7X,'TORP  TORP N',
     *8X,'TORP COORD',5X,'TARGET COORD     RUN',3X,'TORP',/,
     *1X,'NO   COURSE SPEED  RANGE    DA',4X,'COURSE',10X,'X',6X,
     *'Y',7X,'X',6X,'Y',6X,'STOP',2X,'RUN')
C
C     CALCULATE TORPEDO START POSITION (STEP 5)
 160  XTAR=15000.
      YTAR=15000.
      CPA1=RANGE
      BNG=TAC+BEAR
      IF(BNG .GT. PH2)BNG=BNG-PH2
      IF(BNG .LT. 0.)BN=PH2+BNG
      XT=XTAR+RANGE*SIN(BNG)
      YT=YTAR+RANGE*COS(BNG)
      IF(IPRINT .EQ. 1)GO TO 152
      WRITE(6,198)JRUN
 198  FORMAT(1X,/,6X,'RUN NUMBER     :',I4)
C
C     CALCULATE TORPEDO DEFLECTION ANGLE AND FIRING SITUATION
 152  CALL FIRING
C
C     SET DETECTIONTABLES TO ZERO (STEP 6)
      DO 10 I=1,5
      DO  9 J=1,6
      RMAX(I,J)=0.
   9  CONTINUE
  10  CONTINUE
C
C     TEST TORPEDORUN OUT (STEP 7)
      TRUN=TRANGE/TO
      CLOSP=TA*COS(BEAR)+TO*COS(DA)
      HRUN=RANGE/CLOSP
      IF(TRUN .GT. HRUN)GO TO 499
      WRITE(6,231)
 231  FORMAT(1X,/,1X,'TARGET OUTSIDE TORPEDO RANGE')
C
C     ZERO TABLES
      DO 23 J=1,5
```

```
      DETE(JRUN,J)=0.                                                   TORO1450
      DET(JRUN,J)=0.                                                    TORO1460
      ASPEC(JRUN,J)=0.                                                  TORO1470
      CLOSB(JRUN,J)=0.                                                  TORO1480
      DERE(JRUN,J)=0.                                                   TORO1490
   23 CONTINUE                                                          TORO1500
      GO TO 900                                                         TORO1510
  499 IF(IFLAG .EQ. 1)GO TO 990                                         TORO1520
  500 IF(MXT .GE. TRANGE)RUNOUT=1                                       TORO1530
      IF(RUNOUT .EQ. 1)GO TO 990                                        TORO1540
C                                                                       TORO1550
C     CALCULATE NEW POSITIONS                                           TORO1560
      CALL POSIS                                                        TORO1570
C                                                                       TORO1580
C     CHECK IF TARGET IS DETECTED                                       TORO1590
      CALL DETECT                                                       TORO1600
C                                                                       TORO1610
C     CHECK CPA(CLOSEST POINT OF APPROACH) (STEP 8)                     TORO1620
      IL=IL+1                                                           TORO1630
      IF(IL .LE. 20)GO TO 500                                           TORO1640
      IL=0                                                              TORO1650
      CPA=DIST                                                          TORO1660
  155 IF(CPA1-CPA .LE. 0.)RUNOUT=1                                      TORO1670
      CPA1=CPA                                                          TORO1680
      GO TO 500                                                         TORO1690
C                                                                       TORO1700
C     GENERATE STATISTICS (STEP 9)                                      TORO1710
  990 CONTINUE                                                          TORO1720
      DO 910 IKL=1,5                                                    TORO1730
C                                                                       TORO1740
C     KON( ) = DETECTION/NO DETECTION                                   TORO1750
      IF(RMAX(IKL,1) .GT. 1.)KON(JRUN,IKL)=1                            TORO1760
C                                                                       TORO1770
C     DET( ) = DISTANCE TO TARGET AT DETECTION                          TORO1780
      DET(JRUN,IKL)=RMAX(IKL,1)                                         TORO1790
C                                                                       TORO1800
C     DETB( ) = BEARING TO TARGET AT DETECTION                          TORO1810
      DETE(JRUN,IKL)=RMAX(IKL,2)                                        TORO1820
C                                                                       TORO1830
C     ASPEC( ) = TARGET ASPECT AT DETECTION                             TORO1840
      ASPEC(JRUN,IKL)=RMAX(IKL,5)                                       TORO1850
C                                                                       TORO1860
C     CLOSB( ) = BEARING TO CLOSEST PART OF TARGET                      TORO1870
      CLOSB(JRUN,IKL)=RMAX(IKL,4)                                       TORO1880
C                                                                       TORO1890
C     DERE( ) = REL BEARING FROM MAIN TORP COURSE TO TARGET             TORO1900
      DERE(JRUN,IKL)=RMAX(IKL,6)                                        TORO1910
  910 CONTINUE                                                          TORO1920
```

```
      IF(IFLAG .EQ. 1)GO TO 991
C
C     PRINT OUT (STEP 10)
      CCUR=MCCURS/RAD
      TC=TCOURS/RAD
      IT=ITIME/2
      IF(IPRINT .EQ. 0)GO TO 195
      WRITE(6,232)JRUN,TACMG,TAM1,RNGMCC,CA1,COUR,XT,YT,XTAR,YTAR,
     *IT,MXT
  232 FORMAT(1X,/,1X,I3,3X,F5.1,2X,F4.1,1X,F6.0,2X,F5.1,3X,
     *F5.1,7X,F6.0,1X,F6.0,2X,F6.0,1X,F6.0,3X,I4,2X,F6.0)
      IF(RMAX(1,1) .EQ. 0.)GO TO 991
      GO TO 900
  195 WRITE(6,200)IT
  200 FORMAT(1X,'RUN STOPPED AFTER ',I5,' SECONDS',//,
     *1X,'RUN DATA AS FOLLOWS AT END OF RUN')
      WRITE(6,202)MXT,DIST
  202 FORMAT(1X,'TOTAL TORP RUN ',F9.1,/,1X,'DIST TO TARGET ',F9.1)
      WRITE(6,204)XT,YT,XTAR,YTAR,COUR,TC
  204 FORMAT(1X,'TORP X-COORD ',2X,F9.1,4X,'TORP Y-COORD ',2X,F9.1,/,
     *1X,'TARGET X-COORD ',F9.1,4X,'TARGET Y-COORD ',F9.1,/,
     *1X,'TORP MAIN COURSE ',F9.3,6X,'TORP COURSE ',1X,F9.3)
      IF(RMAX(1,1) .EQ. 0.)GO TO 991
      WRITE(6,206)
      WRITE(6,208)(I,(RMAX(I,J),J=1,5),I=1,5)
  206 FORMAT(1X,/,1X,'MAXIMUM DETECTION RANGES AND BEARINGS',
     */,1X,'SUCCESSIVE',4X,'MAX  DET',9X,'DET BEARING',
     *5X,'MAX  DET',11X,'DET BEARING',4X,'TARGET',/,
     *1X,'DET    NO.',4X,'RANGE - CENTER',4X,
     *'CENTER',9X,'RANGE - CLOSEST',4X,'CLOSEST',
     *8X,'ASPECT')
  208 FORMAT(3X,I4,7X,F10.1,7X,F8.2,7X,F10.1,9X,
     *F8.2,7X,F8.2)
      GO TO 900
  991 WRITE(6,220)
C
C     ALL RUN COMPLETED ? (STEP 11)
  900 CONTINUE
C
C     CALCULATE SUMMARY RESULT (STEP 12)
      DO 27 KR=1,5
      DO 28 LR=1,IRUN
      RM(KR,1)=RM(KR,1)+FLOAT(KON(LR,KR))
      RM(KR,2)=RM(KR,2)+DET(LR,KR)
      RM(KR,3)=RM(KR,3)+ABS(ASPEC(LR,KR))
      RM(KR,4)=RM(KR,4)+DETB(LR,KR)
      RM(KR,5)=RM(KR,5)+DERB(LR,KR)
   28 CONTINUE
```

```
 27   CONTINUE                                                          TOR02410
      DO 920 KK=1,5                                                     TOR02420
C                                                                       TOR02430
C     COMPUTING MEANS                                                   TOR02440
      DEL=RM(KK,1)                                                      TOR02450
      IF(DEL .LE. 1.)DEL=1.                                             TOR02460
      RM(KK,2)=RM(KK,2)/DEL                                             TOR02470
      RM(KK,3)=RM(KK,3)/DEL                                             TOR02480
      RM(KK,4)=RM(KK,4)/DEL                                             TOR02490
      RM(KK,5)=RM(KK,5)/DEL                                             TOR02500
920   CONTINUE                                                          TOR02510
C                                                                       TOR02520
C                                                                       TOR02530
      DO 25 KK=1,5                                                      TOR02540
      VAR(KK)=0.                                                        TOR02550
      DO 170 I=1,IRUN                                                   TOR02560
      IF(KCN(I,KK) .EQ. 0)GO TO 170                                     TOR02570
      VAR(KK)=VAR(KK)+((DET(I,KK)-RM(KK,2))**2)                         TOR02580
170   CONTINUE                                                          TOR02590
25    CONTINUE                                                          TOR02600
      DO 26 KR=1,5                                                      TOR02610
      DEL=RM(KR,1)                                                      TOR02620
      IF(DEL .LE. 2.)DEL=2.                                             TOR02630
      STD(KR)=SQRT(VAR(KR)/(DEL-1.))                                    TOR02640
      RM(KR,1)=RM(KR,1)/FLOAT(IRUN)                                     TOR02650
26    CONTINUE                                                          TOR02660
C                                                                       TOR02670
C                                                                       TOR02680
C     PRINT SUMMARY (STEP 13)                                           TOR02690
      WRITE(6,197)JRUN                                                  TOR02700
197   FORMAT(1X,//,6X,'SUMMARY OF RESULT AFTER',3X,I4,2X,'RUNS')        TOR02710
      WRITE(6,199)((RM(I,J),J=1,2),STD(I),(RM(I,J),J=3,5),I=1,5)        TOR02720
199   FORMAT(10X,'PROBABILITY OF DETECTION',8X,                         TOR02730
     *'AVERAGE',6X,'STD DEVIATION',7X,'AVERAGE',7X,'AVERAGE',           TOR02740
     *7X,'AVERAGE',/,41X,                                               TOR02750
     *'DET RANGE',6X,'DET RANGE',7X,'TARGET ASPECT',4X,'DET BEARING',   TOR02760
     *3X,'REL BEARING',/,                                               TOR02770
     *1X,'ONE SUCCESSIVE DETECTION',5X,F6.4,5(6X,F9.4),/,               TOR02780
     *1X,'TWO SUCCESSIVE DETECTIONS',4X,F6.4,5(6X,F9.4),/,              TOR02790
     *1X,'THREE SUCCESSIVE DETECTIONS',2X,F6.4,5(6X,F9.4),/,            TOR02800
     *1X,'FOUR SUCCESSIVE DETECTIONS',3X,F6.4,5(6X,F9.4),/,             TOR02810
     *1X,'FIVE SUCCESSIVE DETECTIONS',3X,F6.4,5(6X,F9.4),/)             TOR02820
220   FORMAT(1X,'NO DETECTION MADE DURING THIS RUN')                    TOR02830
      DA2=DA2/FLOAT(IRUN)                                               TOR02840
      WRITE(6,190)DA2                                                   TOR02850
190   FORMAT(1X,/,1X,'AVERAGE DEFLECTION ANGLE :',5X,F8.4,/)            TOR02860
      WRITE(6,234)                                                      TOR02870
234   FORMAT(1X,/,1X,'DISTRIBUTION OF RUN RESULT - CENTER OF TARGET',/, TOR02880
```

```
     *6X,'ONE SUCCESSIVE DETECTION',10X,'TWO SUCCESSIVE DETECTIONS',     TORO2890
     *8X,'THREE SUCCESSIVE DETECTIONS',/,                                TORO2900
     *2X,'BEAR',2X,'RANGE  ASPECT BEAR CLOS',6X,'BEAR',2X,               TORO2910
     *'RANGE  ASPECT BEAR CLOS',5X,'BEAR',2X,                            TORO2920
     *'RANGE  ASPECT BEAR CLOS')                                         TORO2930
C                                                                        TORO2940
      WRITE(6,236)((DETB(I,1),DET(I,1),ASPEC(I,1),CLOSB(I,1),            TORO2950
     *DETB(I,2),DET(I,2),ASPEC(I,2),CLOSB(I,2),DETB(I,3),                TORO2960
     *DET(I,3),ASPEC(I,3),CLOSB(I,3)),I=1,IRUN)                          TORO2970
 236  FORMAT(3(1X,F6.1,1X,F6.1,1X,F6.1,2X,F6.1,5X))                      TORO2980
 999  STOP                                                               TORO2990
      END                                                                TORO3000
C                                                                        TORO3010
C                                                                        TORO3020
C                                                                        TORO3030
      SUBROUTINE PARMET                                                  TORO3040
C     READING IN DATA AND PARAMETERS                                     TORO3050
      COMMON ISEED2, TTIME, TO, TA, TRATE, RANGE, ALFA, LAMBD, TADEC,    TORO3060
     *BEAR, RAD, TAC, COOR, DEVSP, BNG, PN, PH2, MCOURS, TCOURS,         TORO3070
     *MXT, MXM, IK, IDTIME, ITIME, XT, YT, XTAR, YTAR, TDIST,            TORO3080
     *MDIST, TURNTO, INTVAL, PHI, RMAX(5,6), TRANGE, DIST,IPRINT         TORO3090
      REAL LAMBD, MCOURS, MXT, MXM, MDIST, LAMBDD                        TORO3100
      INTEGER RUNOUT                                                     TORO3110
C                                                                        TORO3120
C     TEDEC - TECHNICAL DETECTION RANGE (STEP A1)                        TORO3130
C     LEVEL OF VARIATION: 375-750-1125-1500 METERS                       TORO3140
C     TADEC - TACTICAL DETECTION RANGE                                   TORO3150
      TEDEC=750.                                                         TORO3160
      TADEC=TEDEC                                                        TORO3170
C                                                                        TORO3180
C     TTIME - TRANSMISSION INTERVAL                                      TORO3190
      TTIME=2.*TEDEC/1500.                                               TORO3200
C                                                                        TORO3210
C     TOKN - TORP SPEED IN KNOTS, TO - TORP SPEED IN M/SEC (STEP A2)     TORO3220
C     LEVEL OF VARIATION:24-32-40 KNOTS                                  TORO3230
      TOKN=40.                                                           TORO3240
      TO=TOKN/2                                                          TORO3250
C                                                                        TORO3260
C     TAKN - TARGET SPEED IN KNOTS, TA - TARGET SPEED IN M/SEC (STEP A3)TORO3270
C     LEVEL OF VARIATION: 12-18-24-30 KNOTS                              TORO3280
      TAKN=18.                                                           TORO3290
      TA=TAKN/2                                                          TORO3300
C                                                                        TORO3310
C     TACG - TARGET COURSE IN DEGREE (STEP A4)                           TORO3320
      TACG=270                                                           TORO3330
      TAC=TACG*RAD                                                       TORO3340
C                                                                        TORO3350
C     ALFAG - SWEEP ANGLE IN DEGREE, ALFA - SWEEP ANGLE IN RADIANS       TORO3360
```

```
C                    (STEP A5)
C       LEVEL OF VARIATION: 20-30-40 DEGREES
        ALFAG=30.
        ALFA=ALFAG*RAD
C
C       LAMBDG - LOBE WIDTH EACH SIDE OF TORP HEADING (STEP A6)
C       LEVEL OF VARIATION: 10-20-30 DEGREES
        LAMBDG=20.
        LAMBD=LAMBDG*RAD
C
C       RELBRG - RELATIVE BEARING FROM TARGET TO TORP IN DEGREE (STEP A7)
C       LEVEL OF VARIATION: 0-30-60-90-120-180 DEGREES
        RELBRG=-60.
        BEAR=RELBRG*RAD
C
C       RANGE - DISTANCE BETWEEN TARGET AND TORP (STEP A8)
C       LEVEL OF VARIATION: 1500-3000-5000-7000 METERS
        RANGE=3000.
C
C       TRANGE - MAX TORP RUN IN METERS (STEP A9)
        TRANGE=18000.
C
C       TRATEG - TORP TURNRATE IN DEGREE PER SEC (STEP A10)
C       LEVEL OF VARIATION: 3-6-9-12-15-18-21 DEGREE/SEC
        TRATEG=18.
        TRATE=TRATEG*RAD
C
C       CALCULATE WIDTH OF TACTICAL SWEEP-LANE (THEORETICAL)
        SRNG=TADEC*SIN(ALFA+LAMBD)*2.
C
C       CALCULATE COVERAGE RATIO (THEORETICAL)
        CRATIO=1.-(TRATE*TTIME/(2.*LAMBD))
C
C       PRINT OF SITUATION AT START OF RUN (STEP A12)
        IF(IPRINT .EQ. 0)GO TO 90
        WRITE(6,110)
  110   FORMAT(1X,//,1X,'TACTICAL SITUATION WHEN FIRING',6X,
       *'TORPEDO PARAMETER',/,
       *2X,'RANGE   ATTACK   TARGET   TARGET',6X,'DET.DET   TORP',
       *3X,'SWEEP   LOBE    TURN   SWEEP    COVERAGE',/,
       *9X,'ANGLE    COURSE   SPEED',7X,'RANGE     SPEED',2X,
       *'ANGLE   WIDTH   RATE   LANE',4X,'RATIO')
        WRITE(6,112)RANGE,RELBRG,TACG,TAKN,TEDEC,TOKN,ALFAG,
       *LAMBDG,TRATEG,SRNG,CRATIO
  112   FORMAT(1X,F6.0,2X,F6.1,3X,F5.1,3X,F4.1,6X,F6.1,3X,F5.1,3X,
       *F4.1,3X,F4.1,2X,F4.1,2X,F6.1,3X,F5.3)
        GO TO 95
   90   WRITE(6,100)
```

```
100   FORMAT(1X,'TACTICAL SITUATION WHEN FIRING',/,1X,                  TORO3850
     *'FIRING RANGE',3X,'ATTACK ANGLE',3X,                              TORO3860
     *'TARGET COURSE',2X,'TARGET SPEED')                                TORO3870
      WRITE(6,102)RANGE,RELBRG,TACG,TAKN                                TORO3880
102   FORMAT(1X,4(2X,F6.1,7X),/)                                        TORO3890
      WRITE(6,104)                                                      TORO3900
104   FORMAT(1X,'TORPEDO PARAMETERS',/,1X,                              TORO3910
     *'TECH.DET.RANGE',2X,'TRANS.INT.VAL',2X,'TORP SPEED',3X,           TORO3920
     *'SWEEP ANGLE')                                                    TORO3930
      WRITE(6,106)TEDEC,TTIME,TOKN,ALFAG                                TORO3940
106   FORMAT(1X,2(2X,F7.2,7X),2(F6.1,7X),/)                             TORO3950
      WRITE(6,108)LAMBDG,TRATEG                                         TORO3960
108   FORMAT(1X,'LOBE WIDTH',6X,'TURN RATE',/,                          TORO3970
     *3X,F6.1,10X,F6.1)                                                 TORO3980
      WRITE(6,109)SRNG,CRATIO                                           TORO3990
109   FORMAT(1X,'THEORETICAL WIDTH OF TACTICAL SWEEP-LANE',F9.1,        TORO4000
     */,1X,'THEORETICAL COVERAGE RATIO',F9.4)                           TORO4010
99    RETURN                                                            TORO4020
      END                                                               TORO4030
C                                                                       TORO4040
C                                                                       TORO4050
C                                                                       TORO4060
      SUBROUTINE FIRING                                                 TORO4070
C     CALCULATE THE TORP DEFLECTION ANGLE, MAIN COURSE, FIRING COURSE   TORO4080
C     BASED ON ESTIMATE OF TARGET DATA(UNCERTAINTY)                     TORO4090
C                                                                       TORO4100
      DIMENSION U(2)                                                    TORO4110
      COMMON ISEED2, TTIME, TO, TA, TRATE, RANGE, ALFA,LAMBD,TADEC,     TORO4120
     *BEAR, RAD, TAC, CCOR, DEVSP, BNG, PN, PH2, MCOURS, TCOURS,        TORO4130
     *MXT, MXM, IK, IDTIME, ITIME, XT, YT, XTAR, YTAR, TDIST,           TORO4140
     *MDIST, TURNTC, INTVAL, PHI, RMAX(5,6), TRANGE, DIST,IPRINT        TORO4150
      COMMON/DATA/DA,OFLOB                                              TORO4160
      COMMON/TARGET/TACMG,TAM1,RNGMOD,CA1,COUR,CE(10),SE(15),JRUN,      TORO4170
     *IFLAG,CA2                                                         TORO4180
      REAL LAMBD, MCOURS, MXT, MXM, MDIST, LAMBDG                       TORO4190
      INTEGER RUNOUT                                                    TORO4200
C                                                                       TORO4210
C                                                                       TORO4220
      PN=-1                                                             TORO4230
      PP=1.                                                             TORO4240
      KSPEED=MOD((JRUN-1),15)+1                                         TORO4250
      KCOURS=IFIX((JRUN-1)/15.)+1                                       TORO4260
      CALL GGUB(ISEED2,2,U)                                             TORO4270
C                                                                       TORO4280
C     CALCULATE ESTIMATE OF TARGET COURSE (STEP B1)                     TORO4290
19    TACM=TAC+CE(KCOURS)                                               TORO4300
20    DIFCC=TACM-TAC                                                    TORO4310
      IF(TACM .GE. PH2)TACM=TACM-PH2                                    TORO4320
```

```
      IF(TACM .LT. 0.)TACM=PH2+TACM                                     TORP04330
C                                                                       TORP04340
C     CALCULATE EST OF TARGET SPEED (STEP B2)                           TORP04350
      TAM=TA+SE(KSPEED)                                                 TORP04360
C                                                                       TORP04370
C     CALCULATE TORPEDO DEFLECTION ANGLE (STEP B3)                      TORP04380
      ASP=BEAR-DIFCO                                                    TORP04390
      IF(ASP .LT. -PHI)ASP=PH2+ASP                                      TORP04400
      TACS=TAM*SIN(ABS(ASP))                                            TORP04410
      DAA=TACS/TC                                                       TORP04420
      IF (DAA .GE. 1.)GO TO 26                                          TORP04430
      DA=ARSIN(DAA)                                                     TORP04440
      DA=SIGN(DA,ASP)                                                   TORP04450
C                                                                       TORP04460
C     CALCULATE TORPEDO MAIN FIRING COURSE (STEP B4)                    TORP04470
      MCCURS=BNG+PHI+DA                                                 TORP04480
   10 IF(MCOURS .GT. PH2)MCCURS=MCCURS-PH2                              TORP04490
      IF(MCOURS .LT. 0.)MCCURS=PH2+MCCURS                               TORP04500
      IF(MCOURS .GT. PH2)GO TO 10                                       TORP04510
C                                                                       TORP04520
C     CALCULATE TORPEDO PRESENT FIRING COURSE (STEP B5)                 TORP04530
      DIFALF=(U(1)*2.*ALFA)-ALFA                                        TORP04540
      TCCURS=MCOURS+DIFALF                                              TORP04550
      IF(TCOURS .GT. PH2)TCCURS=TCCURS-PH2                              TORP04560
      IF(TCOURS .LT. 0.)TCCURS=PH2+TCCURS                               TORP04570
      IF(DIFALF .GE. 0.)PN=-PN                                          TORP04580
C                                                                       TORP04590
C     CALCULATE ESTIMATE OF TARGET RANGE (STEP B6)                      TORP04600
      IF(U(2) .GE. 0.5)PP=-PP                                           TORP04610
      RNGDIF=(1.-U(2))*RANGE*0.15                                       TORP04620
      RNGMCD=RANGE+SIGN(RNGDIF,PP)                                      TORP04630
      TACMG=TACM/RAD                                                    TORP04640
      TAM1=TAM*2                                                        TORP04650
      DA1=DA/RAD                                                        TORP04660
      DA2=DA2+DA1                                                       TORP04670
C                                                                       TORP04680
C     PRINT OUT OF FIRING DATA                                          TORP04690
      IF(IPRINT .EQ. 1)GO TO 25                                         TORP04700
      WRITE(6,122)TACMG,TAM1,RNGMCD                                     TORP04710
  122 FORMAT(1X,'EST OF TARGET DATA FOR FIRING',/,                      TORP04720
     *4X,'COURSE',5X,'SPEED',6X,'RANGE',/,                              TORP04730
     *1X,3(F8.1,3X))                                                    TORP04740
      WRITE(6,124)DA1                                                   TORP04750
  124 FORMAT(1X,'TORP DEFLECTION ANGLE IS    ',F6.2)                    TORP04760
      COUR=MCCURS/RAD                                                   TORP04770
      WRITE(6,125)COUR                                                  TORP04780
  125 FORMAT(1X,'TORPEDO MAIN COURSE',8X,F6.2)                          TORP04790
  126 CONTINUE                                                          TORP04800
```

```
      GO TO 25
26    WRITE(6,30)
30    FORMAT(/,1X,'NOT FEASIBLE TO FIRE DUE TO LOW TORPEDO SPEED')
      IFLAG=1
25    RETURN
      END
C
C
C
C
      SUBROUTINE POSIS
C     IS CALCULATING NEW POSITIONS OF TARGET AND TORPEDO IN
C     EACH TIME STEP
C
      COMMON ISEED2, TTIME, TC, TA, TRATE, RANGE, ALFA, LAMED, TADEC,
     *BEAR, RAD, TAC, CCOR, DEVSP, BNG, PN, PH2, MCOURS, TCOURS,
     *MXT, MXM, IK, IDTIME, ITIME, XT, YT, XTAR, YTAR, TDIST,
     *MDIST, TURNTO, INTVAL, PHI, RMAX(5,6), TRANGE, DIST,IPRINT
      REAL LAMBD, MCOURS, MXT, MXM, MDIST, LAMBDG
      INTEGER RUNCUT
C
C     TIME COUNT (STEP C1)
      IK=IK+1
      ITIME=ITIME+IDTIME
C
C     CALCULATE TOTAL TORP RUN  AND TARGET RUN (STEP C2)
      MXT=MXT+TDIST
      MXM=MXM+MDIST
C
C     CALCULATE NEW POSITIONS (STEP C3)
      XT=XT+SIN(TCOURS)*TDIST
      YT=YT+COS(TCOURS)*TDIST
      XTAR=XTAR+SIN(TAC)*MDIST
      YTAR=YTAR+COS(TAC)*MDIST
C
C     CALCULATE NEW TORP COURSE (STEP C4)
      TXCOUR=TCOURS+SIGN(TURNTO,PN)
      TXCDIF=ABS(MCOURS-TXCOUR)
      IF(TXCDIF .GT. PHI)TXCDIF=PH2-TXCDIF
      IF(TXCDIF .LE. ALFA)GO TO 15
      PN=-PN
      ALFADI=TXCDIF-ALFA
      TXCOUR=TXCOUR+2.*SIGN(ALFADI,PN)
15    TCOURS=TXCOUR
      IF(TCOURS .GT. PH2)TCOURS=TCOURS-PH2
      IF(TCOURS .LT. 0.)TCOURS=PH2+TCOURS
25    RETURN
      END
```

```
C
C
C
      SUBROUTINE DETECT
C     TO CHECK IF TARGET IS DETECTED AND STORE DETECTION DATA
C
      COMMON ISEED2, TTIME, TC, TA, TRATE, RANGE, ALFA, LAMBD, TADEC,
     *BEAR, RAD, TAC, CCOR, DEVSP, BNG, FN, PH2, MCCURS, TCCURS,
     *MXT, MXM, IK, IDTIME, ITIME, XT, YT, XTAR, YTAR, IDIST,
     *MDIST, TURNTO, INTVAL, PHI, RMAX(5,6), TRANGE, DIST,IPRINT
      COMMON/DATA/DA,OFLOB
      REAL LAMBD, MCOURS, MXT, MXM, MDIST, LAMBDD
      INTEGER RUNOUT
      DIMENSION DE(3,2)
      DOUBLE PRECISION PCWMAX,B,REX,REX1,REX2,X1,X2,X3,XX1,
     *V1,V2,V,U,FIFACT,X01,X02,X03,XX2,POWER,RELB,ALAM
C
C     SETTING OF TARGET DIMENSION, A - TARGET LENGTH,
C
C     B - TARGET WIDTH,C  - TARGET DEPTH. (STEP D1)
      A=100.
      B=15.
      C=4.
C
C
C     CHECK IF TRANSMISSION (STEP D2)
      IF(IK .LT. INTVAL)GO TO 20
      IK=0
C
C     CALCULATE RANGE TO TARGET (STEP D3)
      DIFX=XTAR-XT
      DIFY=YTAR-YT
      DIST=SQRT((DIFX**2)+(DIFY**2))
C
C     TEST IF TARGET IS WITHIN POSSIBLE DETECTION RANGE
      IF(DIST .GT. (TADEC+A/2.))GO TO 20
C
C     DETECTION THRESHOLD (STEP D4)
      PCWMAX=1./(B*TADEC)**4
      U=SCALE(PHI/2.)
      CONST=(A**2)*(B**2)*(C**2)
      PCWMAX=CONST*PCWMAX*U
C
C     CALCULATE TIME TO TARGET (STEP D5)
      TIMDL1=DIST/1500.
      XTAR1=XTAR+SIN(TAC)*(TIMDL1*TA)
      YTAR1=YTAR+COS(TAC)*(TIMDL1*TA)
C
```

```
C     CENTB - BEARING OF CENTER OF LOBE (STEP D6)
      CC=-CA*CFLCB
      CENTB=TCCURS+DD
      IF(CENTB .LT. 0.)CENTB=PH2+CENTB
      IF(CENTB .GT. PH2)CENTB=CENTB-PH2
C
C     CALCULATE BEARINGS TO TARGET (STEP D7)
      RB=BEARIN(XTAR1,YTAR1,XT,YT)
      XTAR2=XTAR1+SIN(TAC)*A/2.
      YTAR2=YTAR1+COS(TAC)*A/2.
      DIST1=SQRT((XTAR2-XT)**2 + (YTAR2-YT)**2)
      RB1=BEARIN(XTAR2,YTAR2,XT,YT)
      XTAR3=XTAR1-SIN(TAC)*A/2.
      YTAR3=YTAR1-COS(TAC)*A/2.
      DIST2=SQRT((XTAR3-XT)**2 + (YTAR3-YT)**2)
      RB2=BEARIN(XTAR3,YTAR3,XT,YT)
      REL1=RB1-CENTB
      IF(REL1 .GT. PHI)REL1=REL1-PH2
      IF(REL1 .LT. -PHI)REL1=PH2+REL1
      REL0=RB-CENTB
      IF(REL0 .GT. PHI)REL0=REL0-PH2
      IF(REL0 .LT. -PHI)REL0=PH2+REL0
      REL2=RB2-CENTB
      IF(REL2 .GT. PHI)REL2=REL2-PH2
      IF(REL2 .LT. -PHI)REL0=PH2+REL2
C
C     CALCULATE TRANSMISSION GAIN FACTOR (STEP D8)
      RBX1=REL1
      RBX=REL0
      RBX2=REL2
      ALAM=LAMBD
C
C     COMPUTE SEPARATE GAIN FACTORS (STEP D9)
      X1=XFACT(RBX1,ALAM)
      X2=XFACT(RBX,ALAM)
      X3=XFACT(RBX2,ALAM)
      XX1=(X1+X2+X3)/3.
C
C     CALCULATE TARGET ASPECT AND TARGET SONAR CROSS-
C     AREA (TARGET STRENGTH) DUE TO ASPECT (STEP D10)
      ANTRB=RB+PHI
      IF(ANTRB .GT. PH2)ANTRB=ANTRB-PH2
      RELA=ANTRB-TAC
      IF(RELA .GT. PHI)RELA=PH2-RELA
      IF(RELA .LT. -PHI)RELA=PH2+RELA
      RELB=ABS(RELA)
      V1=(A**2)*(DCOS(RELB)**2)
      V2=(B**2)*(DSIN(RELB)**2)
```

```
      V=(V1+V2)**2                                                      TORO6250
C                                                                       TORO6260
C     COMPUTE SCALING FACTOR DUE TO ASPECT (STEP D11)                   TORO6270
      L=SCALE(RELB)                                                     TORO6280
      FIFACT=L/V                                                        TORO6290
C                                                                       TORO6300
C     CALCULATE RETURNTIME FOR ECHO (STEP D12)                          TORO6310
      TIMDL2=2.*TIMDL1                                                  TORO6320
C                                                                       TORO6330
C     CALCULATE REL BEARING FOR RETURNING ECHO (STEP D13)               TORO6340
      TURNST=TRATE*TIMDL2                                               TORO6350
      TXC=TCOURS+SIGN(TURNST,FN)                                        TORO6360
      TXDC=ABS(MCOURS-TXC)                                              TORO6370
      IF(TXDC .GT. PHI)TXDC=PH2-TXDC                                    TORO6380
      IF(TXDC .LE. ALFA)GO TO 18                                        TORO6390
      ALF=TXDC-ALFA                                                     TORO6400
      RELTO=RELO-SIGN((TURNST-ALF),PN)+SIGN(ALF,FN)                     TORO6410
      GO TO 19                                                          TORO6420
   18 RELTO=RELO-SIGN(TURNST,FN)                                        TORO6430
   19 RELDIF=RELTO-RELO                                                 TORO6440
      RELT1=REL1+RELDIF                                                 TORO6450
      RELT2=REL2+RELDIF                                                 TORO6460
      IF(RELTO .GT. PHI)RELTO=PH2-RELTO                                 TORO6470
      IF(RELTO .LT. -PHI)RELTO=PH2+RELTO                                TORO6480
      IF(RELT1 .GT. PHI)RELT1=PH2-RELT1                                 TORO6490
      IF(RELT1 .LT. -PHI)RELT1=PH2+RELT1                                TORO6500
      IF(RELT2 .GT. PHI)RELT2=PH2-RELT2                                 TORO6510
      IF(RELT2 .LT. -PHI)RELT2=PH2+RELT2                                TORO6520
C                                                                       TORO6530
C     TEST FOR DOPPLER                                                  TORO6540
      FRQDEF=50.*2.*(TO*COS(DD)-1.)/1500.                               TORO6550
      FRQDIF=50.*2.*(TO*COS(DD)+1.)/1500.                               TORO6560
      RELC=RELB                                                         TORO6570
      FRQSH=50.*2.*(TO*COS(DD)+TA*COS(RELC))/1500.                      TORO6580
      IF((FRQSH .LT. FRQDIF) .AND. (FRQSH .GT. FRQDEF))GO TO 20         TORO6590
C                                                                       TORO6600
C     CALCULATE RANGE AND BEARING TO CLOSEST PART OF TARGET (STEP D14)  TORO6610
      DB(1,1)=DIST                                                      TORO6620
      DB(1,2)=RELTO+DD                                                  TORO6630
      DB(2,1)=DIST1                                                     TORO6640
      DB(2,2)=RELT1+DD                                                  TORO6650
      DB(3,1)=DIST2                                                     TORO6660
      DB(3,2)=RELT2+DD                                                  TORO6670
      DMIN=DB(1,1)                                                      TORO6680
      MD=1                                                              TORO6690
      IF(DMIN .GT. DB(2,1))GO TO 10                                     TORO6700
    9 IF(DMIN .GT. DB(3,1))GO TO 11                                     TORO6710
      GO TO 12                                                          TORO6720
```

```
10    CMIN=CB(2,1)                                                       TORO6730
      MC=2                                                               TORO6740
      GO TO 9                                                            TORO6750
11    CMIN=CB(3,1)                                                       TORO6760
      MC=3                                                               TORO6770
12    BREL=CB(MC,2)                                                      TORO6780
      IF(BREL .GT. PHI)BREL=PH2-BREL                                     TORO6790
      IF(BREL .LT. -PHI)BREL=PH2+BREL                                    TORO6800
C                                                                        TORO6810
C     CALCULATE RECEIVING GAIN FACTOR (STEP D15)                         TORO6820
      REX1=RELT1                                                         TORO6830
      REX=RELTO                                                          TORO6840
      REX2=RELT2                                                         TORO6850
      XC1=XFACT(REX1,ALAM)                                               TORO6860
      XC2=XFACT(REX,ALAM)                                                TORO6870
      XC3=XFACT(REX2,ALAM)                                               TORO6880
      XX2=(XC1+XC2+XO3)/3.                                               TORO6890
C                                                                        TORO6900
C     CALCULATE FRACTION OF POWER IN TO RECIEVER (STEP D16)              TORO6910
      POWER=CONST*XX1*XX2*FIFACT/(DIST**4)                               TORO6920
C                                                                        TORO6930
C     TEST FOR DETECTION THRESHOLD (STEP D17)                            TORO6940
      IF(POWER .LT. POWMAX)GO TO 15                                      TORO6950
C                                                                        TORO6960
C     COMPUTE BEARING RATE (STEP D18)                                    TORO6970
      ASP=RB+PHI-TAC                                                     TORO6980
      IF(ASP .GT. PHI)ASP=ASP-PH2                                        TORO6990
      IF(ASP .LT. -PHI)ASP=PH2+ASP                                       TORO7000
      AP=ASP*RELTO                                                       TORO7010
      TACS=TA*SIN(ABS(ASP))                                              TORO7020
      TOCS=TO*SIN(ABS(RELTO))                                            TORO7030
      BRATE=(TACS+SIGN(TOCS,AP))/DIST                                    TORO7040
C                                                                        TORO7050
C     CHECK BEARING RATE AGAINST TURNRATE (STEP D19)                     TORO7060
      IF(BRATE .GE. TRATE)GO TO 15                                       TORO7070
C                                                                        TORO7080
C                                                                        TORO7090
C     CHECK TORPEDO SPEED ADVANTAGE (STEP D20)                           TORO7100
      TALS=TA*COS(ABS(ASP))                                              TORO7110
      TOLS=TO*COS(ABS(RELTO))                                            TORO7120
      IF(ABS(ASP) .GT. PHI/2.)TALS=-TALS                                 TORO7130
      IF(ABS(RELTO) .GT. PHI/2.)TOLS=-TOLS                               TORO7140
      IF((TALS+TOLS) .LE. 0.)GO TO 15                                    TORO7150
C                                                                        TORO7160
      RLB=RB-MCOURS                                                      TORO7170
      IF(RLB .GT. PHI)RLB=RLB-PH2                                        TORO7180
      IF(RLB .LT. -PHI)RLB=PH2+RLB                                       TORO7190
C                                                                        TORO7200
```

```
C                                                                       TORO7210
C                                                                       TORO7220
C       STORE DETECTION DATA (STEP D21)                                 TORO7230
        JCONT=JCONT+1                                                   TORO7240
        JMAX=MAX0(JMAX,JCONT)                                           TORO7250
        ICONT=JCONT                                                     TORO7260
        IF(ICONT .GE. 5)ICONT=5                                         TORO7270
C                                                                       TORO7280
C       STORE DATA IN ACCORDANCE WITH NUMBER SUCCESSIVE                 TORO7290
C       DETECTIONS (STEP D22)                                           TORO7300
 25     GO TO(30,31,32,33,34),ICONT                                     TORO7310
 30     IF(RMAX(1,1) .NE. 0.)GO TO 20                                   TORO7320
        RMAX(1,1)=DIST                                                  TORO7330
        RMAX(1,2)=(RELTO+DD)/RAD                                        TORO7340
        IF(RMAX(1,2) .GT. 180.)RMAX(1,2)=RMAX(1,2)-360.                 TORO7350
        RMAX(1,3)=DMIN                                                  TORO7360
        RMAX(1,4)=BREL/RAD                                              TORO7370
        RMAX(1,5)=RELA/RAD                                              TORO7380
        RMAX(1,6)=RLB/RAD                                               TORO7390
        GO TO 20                                                        TORO7400
 31     IF(RMAX(2,1) .NE. 0.)GO TO 20                                   TORO7410
        RMAX(2,1)=DIST                                                  TORO7420
        RMAX(2,2)=(RELTO+DD)/RAD                                        TORO7430
        IF(RMAX(2,2) .GT. 180.)RMAX(2,2)=RMAX(2,2)-360.                 TORO7440
        RMAX(2,3)=DMIN                                                  TORO7450
        RMAX(2,4)=BREL/RAD                                              TORO7460
        RMAX(2,5)=RELA/RAD                                              TORO7470
        RMAX(2,6)=RLB/RAD                                               TORO7480
        GO TO 20                                                        TORO7490
 32     IF(RMAX(3,1) .NE. 0.)GO TO 20                                   TORO7500
        RMAX(3,1)=DIST                                                  TORO7510
        RMAX(3,2)=(RELTO+DD)/RAD                                        TORO7520
        IF(RMAX(3,2) .GT. 180.)RMAX(3,2)=RMAX(3,2)-360.                 TORO7530
        RMAX(3,3)=DMIN                                                  TORO7540
        RMAX(3,4)=BREL/RAD                                              TORO7550
        RMAX(3,5)=RELA/RAD                                              TORO7560
        RMAX(3,6)=RLB/RAD                                               TORO7570
        GO TO 20                                                        TORO7580
 33     IF(RMAX(4,1) .NE. 0.)GO TO 20                                   TORO7590
        RMAX(4,1)=DIST                                                  TORO7600
        RMAX(4,2)=(RELTO+DD)/RAD                                        TORO7610
        IF(RMAX(4,2) .GT. 180.)RMAX(4,2)=RMAX(4,2)-360.                 TORO7620
        RMAX(4,3)=DMIN                                                  TORO7630
        RMAX(4,4)=BREL/RAD                                              TORO7640
        RMAX(4,5)=RELA/RAD                                              TORO7650
        RMAX(4,6)=RLB/RAD                                               TORO7660
        GO TO 20                                                        TORO7670
 34     IF(RMAX(5,1) .NE. 0.)GO TO 20                                   TORO7680
```

```
      RMAX(5,1)=DIST                                                    TORO7690
      RMAX(5,2)=(RELTO+DD)/RAD                                          TORO7700
      IF(RMAX(5,2) .GT. 180.)RMAX(5,2)=RMAX(5,2)-360.                   TORO7710
      RMAX(5,3)=DMIN                                                    TORO7720
      RMAX(5,4)=BREL/RAD                                                TORO7730
      RMAX(5,5)=RELA/RAD                                                TORO7740
      RMAX(5,6)=RLB/RAD                                                 TORO7750
      GO TO 20                                                          TORO7760
C                                                                       TORO7770
C     IF NO DETECTION, SET DETECTION STATUS                             TORO7780
C                                                                       TORO7790
   15 ICCNT=0                                                           TORO7800
      JCCNT=0                                                           TORO7810
   20 RETURN                                                            TORO7820
      END                                                               TORO7830
C                                                                       TORO7840
C                                                                       TORO7850
C                                                                       TORO7860
C                                                                       TORO7870
C                                                                       TORO7880
      FUNCTION BEARIN(A,B,C,D)                                          TORO7890
C     TO CALCULATE BEARING FROM TORPEDO TO TARGET                       TORO7900
      DIFX=A-C                                                          TORO7910
      DIFY=B-D                                                          TORO7920
      PH2=2.*3.141592654                                                TORO7930
      RAD=PH2/360.                                                      TORO7940
      IF(DIFY .NE. 0.)GO TO 16                                          TORO7950
      RB=90.*RAD                                                        TORO7960
      IF(DIFX .LT. 0.)RB=RB+(180.*RAD)                                  TORO7970
      GO TO 17                                                          TORO7980
   16 RB=ATAN2(DIFX,DIFY)                                               TORO7990
      IF(RB .LT. 0.)RB=RB+PH2                                           TORO8000
   17 BEARIN=RB                                                         TORO8010
      RETURN                                                            TORO8020
      END                                                               TORO8030
C                                                                       TORO8040
C                                                                       TORO8050
C                                                                       TORO8060
      FUNCTION XFACT(X,Y)                                               TORO8070
C     CALCULATE REDUCTION-FACTOR IN TRANSDUCER GAIN DUE                 TORO8080
C     TO RELATIVE BEARING OFF CENTER-HEADING OF TORPEDO                 TORO8090
      DOUBLE PRECISION X,XFACT,XY,Y                                     TORO8100
      PHI=3.141592654                                                   TORO8110
      IF(X .EQ. 0.)GO TO 10                                             TORO8120
      XY=X/Y                                                            TORO8130
      XFACT=DABS((DCOS(X*0.5)*DSIN(XY*PHI))/(XY*PHI))                   TORO8140
      RETURN                                                            TORO8150
   10 XFACT=1.                                                          TORO8160
```

```
      RETURN
      END
C
C
C
      FUNCTION SCALE(Y)
C     CALCULATE SCALING FACTOR IN THE PROCESS OF
C     COMPUTING TARGET STRENGTH
      DOUBLE PRECISION SCALE,RELB,Z,Y
C
      PHI=3.151592654
      IF(Y .GT. PHI/2.)Y=PHI-Y
      Z=0.251635*(Y**2) - 0.18555*Y
      Z=Z+0.0365*DSIN(3.*(Y+0.17453)) + 0.015*(Y**2)*DSIN(9.*Y/2.)
      SCALE=1./Z
      RETURN
      END
```

APPENDIX B

FLOW CHART FOR SIMULATION PROGRAM

```
A TORPEDO SIMULATION.     MAIN PROGRAM.                          PAGE    1
                         |
        A TORPEDO SIMULATION.     MAIN PROGRAM.

        A TORPEDO SIMULATION.

        SIMULATING AN ACTIVE HOMING TORPEDO DURING SEARCH.

        THE PROGRAM IS RUN IN 0.5 SEC STEPS.

            COMMON ISEED2, TTIME, TO, TA, TRATE, RANGE, ALFA, LAMBC, TADEC,
            BEAR, RAD, TAC, CCOR, DEVSP, ENG, EN, PH2, MCOURS, TCOURS,
            MXT, MXM, IK, IDTIME, ITIME, XT, YT, XTAR, YTAR, TDIST, MDIST,
            TURNTO, INTVAL, PHI, RMAX(5,6),TRANGE, DIST,IPRINT

            COMMON/DATA/DA,OPLOB

            COMMON/TARGET/TACMG,TAM1,RNGMOD,DA1,COUR,CE(10),SE(15),JRUN,
            IFLAG,DA2

            DIMENSION RM(5,5), VAR(5), DET(150,5), DETB(150,5),STD(5),
            ASPEC(150,5),DERB(150,5),CLOSB(150,5),KON(150,5)

            REAL LAMBC, MCOURS, MXT, MXM, MDIST, LAMBDG

            INTEGER RUNOUT


        SETTING OF CONSTANTS (STEP 1)

            CALL OVPLOW
                      |
            ----------------------------------------------
            | PHI   =3.141592654                         |
            | PH2   =2.*PHI                              |
            | RAD   =PH2/360.                            |
            | ISEED1 =362776                             |
            | ISEED2 =961695                             |
            ----------------------------------------------
                      |
        CCOREC  -  MAX ERROR IN TARGET COURSE ESTIMATE
                      |
            ----------------------------------------------
            | CCOREC =15.                                |
            | CCOR =CCOREC*RAD                           |
            ----------------------------------------------
                      |
        DSPEED  -  ST DEV IN TARGET SPEED ESTIMATE
                      |
            ----------------------------------------------
            | DSPEED =3.                                 |
            | DEVSP=DSPEED*0.5                           |
            | IDTIME =1                                  |
            ----------------------------------------------
                      |


        SET NUMBER OF ITERATIONS
                      |
            ----------------------------------------------
            | IRUN =150                                  |
            ----------------------------------------------
                      |
```

(CONTINUED ON PAGE   2)

```
                  |


      SET PRINT OUT MODE

                  |
         ------------------------------------
         | IPRINT =1                        |
         ------------------------------------
                  |


      SET LOBE OFF TORPEDO CENTER BEARING

                  |
         ------------------------------------
         | CFLOB=0.                         |
         ------------------------------------
                  |


      SET TABLES TO ZERO (STEP 2)

                  |
            +-----------+
           + DO          +
  +++++++++    11          +
  +        + I=1,5       +
  +         +------------+
  +               |
  +               |
  +         +------------+
  +        + DO          +
  +++++++++    12          +
  +        + J=1,5       +
  +         +------------+
  +               |
  +               |
  +      ------------------------------------
  +      | BM(I,J) =0.                      |
  +      ------------------------------------
  +               |
  +
12 ++++++++CONTINUE
  +
11 ++++++++CONTINUE
                  |
            +-----------+
           + DO          +
  +++++++++    13          +
  +        + J=1,5       +
  +         +------------+
  +               |
  +               |
  +         +------------+
  +        + DO          +
  +++++++++    14          +
  +        + I=1,IRUN    +
  +         +------------+
  +               |
  +               |
  +      ------------------------------------
  +      | KCN(I,J) =0                      |
  +      ------------------------------------
  +               |
  +
14 ++++++++CONTINUE
  +
13 ++++++++CONTINUE
                  |
         ------------------------------------
         | DA2  =0.                         |
         ------------------------------------
                  |
```

(CONTINUED ON PAGE   3)

```
                         |


      COMPUTE TARGET ERRORS AND STORE
                         |
                  +------------------+
                  + DO                +
 ++++++++++             20             +
 +                + I=1,10            +
 +                +------------------+
 +                       |
 +                       |
 +             ---------------------------------------------------
 +             | CE(I)=-(15.*RAD+CCOR/10.)+(CCOR               |
 +             |        /10.)*I*2.                              |
 +             ---------------------------------------------------
 +                       |
 +
 20 ++++++++CONTINUE
                         |
               ---------------------------------------------------
               | SE(1)=-1.8737*DEVSP                            |
               | SE(2)=-1.2825*DEVSP                            |
               | SE(3)=-0.968*DEVSP                             |
               | SE(4)=-0.7285*DEVSP                            |
               | SE(5)=-0.525*DEVSP                             |
               | SE(6)=-0.34*DEVSP                              |
               | SE(7)=-0.1675*DEVSP                            |
               | SE(8)=0*DEVSP                                  |
               | SE(9)=0.1675*DEVSP                             |
               | SE(10)  =0.34*DEVSP                            |
               | SE(11)  =0.525*DEVSP                           |
               | SE(12)  =0.7285*DEVSP                          |
               | SE(13)  =0.968*DEVSP                           |
               | SE(14)  =1.2825*DEVSP                          |
               | SE(15)  =1.8737*DEVSP                          |
               ---------------------------------------------------
                         |



                         |
                  +------------------+
 100              + DO                +
 ++++++++++          900               +
 +                + JRUN=1,IRUN       +
 +                +------------------+
 +                       |
 +
 +    SET RUN COUNTERS (STEP 3)
 +
 +
 +
 +
 +
 +    IFLAG=1; TOO LOW TORPEDO SPEED
 +
 +                       |
 +             ---------------------------------------------------
 +             | IFLAG=0                                        |
 +             | ICONT=0                                        |
 +             | JCONT=0                                        |
 +             | ITIME=0                                        |
 +             | IL    =0                                       |
 +             | IK    =0                                       |
 +             | DIST  =0.                                      |
 +             | MXT   =0.                                      |
 +             | MXM   =0.                                      |
 +             | RUNOUT =0                                      |
 +             ---------------------------------------------------
 +                       |
 +                       |
```
(CONTINUED ON PAGE   4)

```
          +                    |
          +
          +
          +   READ IN SETTING(TORP AND TACTICAL)
          +
          +   FIRST RUN ? (STEP 4)
          +                    |
          +                    |
          +             . *  *  * .
          +         . *     IF       * .
          +        *     JRUN.GT.1       *
          +        * .                 . *-------------------
          +          * .             . *          T      | 160  |
          +              *   .   *                        -------
          +                    |
          +                    F
          +                    |
          +                    |
          +
          +      CALL PARMET
          +
          +
          +    ***WRITE(6,228)CFLOB
    228   +      FORMAT(1X,/,1X,'SONAR MAIN LOBE OFF-SET FROM CENTER ',
          +      'BEARING',F6.2,' TIMES DEFLECTION ANGLE',/)
          +                    |
          +      -------------------------------------------
          +      | IDIST=TC/2.                             |
          +      | MDIST=TA/2.                             |
          +      | TURNTC =TRATE/2.                        |
          +      | INTVAL =IFIX((TTIME/0.5)+0.5)           |
          +      -------------------------------------------
          +                    |
          +   INTVAL GIVES NUMBER OF TIMESTEPS FOR EACH TRANSMISSION
          +
          +
          +
          +                    |
          +                    |
          +             . *  *  * .
          +         . *     IF       * .
          +        *     IPRINT.EQ.0     *
          +        * .                 . *-------------------
          +          * .             . *          T      | 160  |
          +              *   .   *                        -------
          +                    |
          +                    F
          +                    |
          +                    |
          +
          +
          +   PRINT OF HEADING
          +
    151   +    ***WRITE(6,230)
    230   +      FORMAT(1X,//,1X,'RUN',4X,'EST OF TARGET',7X,'TORP  TORP M',
          +      8X,'TORP COORD',5X,'TARGET COORD     RUN',3X,'TORP',/,
          +      1X,'NO   COURSE SPEED  RANGE   DA',4X,'COURSE',10X,'X',6X,
          +      'Y',7X,'X',6X,'Y',6X,'STOP',2X,'RUN')
          +                    |
```

(CONTINUED ON PAGE   5)

```
         +
         +                    |
         +
         +
         +
         +   CALCULATE TORPEDO START POSITION (STEP 5)
         +
         +                    |
         +      ----------------------------------------
   160   +      | XTAR =1500C.                          |
         +      | YTAR =1500C.                          |
         +      | CPA1 =RANGE                           |
         +      | BNG  =TAC+BEAR                        |
         +      ----------------------------------------
         +                    |
         +                    |
         +                    |
         +               . *     * .
         +           . *     IF      * .
         +         *    BNG.GT.PH2       *
         +         * .                 . *-----------------------------
         +             * .         . *         T    | BNG=BNG-PH2
         +                 *  .  *                  ------------------------
         +                    |                          |
         +                    F                          |
         +                    |---------------------------
         +                    |
         +                    |
         +                    |
         +               . *     * .
         +           . *     IF      * .
         +         *     BNG.LT.C.       *
         +         * .                 . *-----------------------------
         +             * .         . *         T    | BN=PH2+BNG
         +                 *  .  *                  ------------------------
         +                    |                          |
         +                    F                          |
         +                    |---------------------------
         +                    |
         +                    |
         +      ----------------------------------------
         +      | XT    =XTAR+RANGE*SIN(BNG)            |
         +      | YT    =YTAR+RANGE*COS(BNG)            |
         +      ----------------------------------------
         +                    |
         +                    |
         +                    |
         +               . *     * .
         +           . *     IF      * .
         +         *    IPRINT.EQ.1      *
         +         * .                 . *------------------
         +             * .         . *         T    | 152  |
         +                 *  .  *                  -------
         +                    |
         +                    F
         +                    |
         +                    |
         +    ***WRITE(6,198)JRUN
         +
   198   +      FORMAT(1X,/,6X,'RUN NUMBER     :',I4)
         +
         +
         +
         +
         +   CALCULATE TORPEDO DEFLECTION ANGLE AND FIRING SITUATION
         +
         +
   152   +      CALL FIRING
         +                    |
```

(CONTINUED ON PAGE   6)

```
     +
     +                   |
     +
     +
     +
     +
     +   SET DETECTIONTABLES TO ZERO (STEP 6)
     +
     +                   |
     +            +-------------+
     +           + DO            +
     ++++++++++       10          +
     +           + I=1,5         +
     +            +-------------+
     +                   |
     +                   |
     +            +-------------+
     +           + DO            +
     ++++++++++       9           +
     +           + J=1,6         +
     +            +-------------+
     +                   |
     +                   |
     +        ----------------------------------------
     +        | FMAX(I,J) =0.                        |
     +        ----------------------------------------
     +                   |
     +
   9 ++++++++CONTINUE
     +
  10 ++++++++CONTINUE
     +
     +
     +
     +
     +   TEST TORPEDORUN OUT (STEP 7)
     +
     +                   |
     +        ----------------------------------------
     +        | TRUN =TRANGE/TO                      |
     +        | CLOSP=TA*COS(BEAR) +TO*COS(DA)       |
     +        | BRUN =RANGE/CLOSP                    |
     +        ----------------------------------------
     +                   |
     +                   |
     +                   |
     +              . *     * .
     +          . *     IF      * .
     +        *   TRUN.GT.HRUN     *
     +        * .               . *-----------------
     +          * .           . *        T    | 499  |
     +              *   .   *                 ------
     +                  |
     +                  F
     +                  |
     +                  |
     +    ***WRITE(6,231)
     +
 231 +       FORMAT(1X,/,1X,'TARGET OUTSIDE TORPEDO RANGE')
     +
     +
     +
     +   ZERO TABLES
     +
     +                   |
     +            +-------------+
     +           + DO            +
     ++++++++++       23          +
     +           + J=1,5         +
     +            +-------------+
     +                   |
     +                   |
     +        ----------------------------------------
     +        | DETB(JRUN,J) =0.                     |
     +        ----------------------------------------
     +                   |
```

(CONTINUED ON PAGE   7)

```
      +
      +              |
      +        DET(JRUN,J)=0.
      +              |
      +        --------------------------------------
      +        | ASPEC(JRUN,J) =0.                   |
      +        | CLOSB(JRUN,J) =0.                   |
      +        | DERE(JRUN,J) =0.                    |
      +        --------------------------------------
      +              |
      +
 23   +++++++CCNTINUE
      +              |
      +          ------
      +          | 900 |
      +          ------
      +
      +
      +              |
      +              |
 499  +        . *       * .
      +      . *     IF      * .
      +     *     IFLAG.EQ.1     *
      +     * .                . *-----------------
      +       * .            . *        T    | 990  |
      +         * .        . *               -------
      +              |
      +              F
      +              |
      +              |
      +              |
 500  +        . *       * .
      +      . *     IF      * .
      +     *   MXT.GE.TRANGE    *
      +     * .                . *-----------------------------------
      +       * .            . *        T    | RUNOUT=1
      +         * .        . *               ---------------------
      +              |                              |
      +              F                              |
      +              |-------------------------------
      +              |
      +              |
      +        . *       * .
      +      . *     IF      * .
      +     *     RUNOUT.EQ.1    *
      +     * .                . *-----------------
      +       * .            . *        T    | 990  |
      +         * .        . *               -------
      +              |
      +              F
      +              |
      +
      +
      +
      +  CALCULATE NEW POSITIONS
      +
      +      CALL POSIS
      +
      +
      +
      +  CHECK IF TARGET IS DETECTED
      +
      +
```

(CONTINUED ON PAGE   8)

```
         +                  |
         +
         +       CALL DETECT
         +
         +
         +
         +    CHECK CPA(CLOSEST POINT OF APPROACH)  (STEP 8)
         +
         +                  |
         +       -------------------------------------------
         +       | IL    =IL+1                             |
         +       -------------------------------------------
         +                  |
         +                  |
         +                  |
         +            . *   * .
         +        . *    IF     * .
         +      *     IL.LE.20       *
         +      * .                . *--------------------
         +        * .            . *         T     | 500  |
         +            * . *                        -------
         +                  |
         +                  F
         +                  |
         +                  |
         +                  |
         +       -------------------------------------------
         +       | IL    =0                                |
         +       | CPA   =DIST                             |
         +       -------------------------------------------
         +                  |
         +                  |
         +                  |
155      +            . *   * .
         +        . *    IF     * .
         +      *  CPA1-CPA.LE.0.    *
         +      * .                . *----------------------------------------
         +        * .            . *         T     | RUNOUT=1
         +            * . *                        ---------------------------
         +                  |                            |
         +                  F                            |
         +                  |-----------------------------
         +                  |
         +                  |
         +       -------------------------------------------
         +       | CPA1  =CPA                              |
         +       -------------------------------------------
         +                  |
         +                  |
         +               -------
         +               | 500 |
         +               -------
         +
         +
         +
         +
         +
         +    GENERATE STATISTICS  (STEP 9)
         +
990      +       CONTINUE
         +                  |
         +           +-------------+
         +          + DO            +
         ++++++++++      910          +
         +          + IKL=1,5       +
         +           +-------------+
         +                  |
         +
```

(CONTINUED ON PAGE   9)

```
      +
      +                    |
      +
      +
      +
      +   KON( ) = DETECTION/NO DETECTION
      +
      +                    |
      +                    |
      +              .  *     *  .
      +          .  *     IF      *  .
      +      * RMAX(IKL,1).GT.1.      *
      +      *  .                    .  *-------------------------------------
      +          *  .             .  *        T     | KON(JRUN,IKL)=1
      +              *     .     *                  -------------------------
      +                    |                              |
      +                    F                              |
      +                    |-------------------------------
      +                    |
      +
      +
      +
      +   DET( ) = DISTANCE TO TARGET AT DETECTION
      +
      +                    |
      +       ------------------------------------------
      +       | DET(JRUN,IKL) =RMAX(IKL,1)             |
      +       ------------------------------------------
      +                    |
      +
      +
      +
      +   DETB( ) = BEARING TO TARGET AT DETECTION
      +
      +                    |
      +       ------------------------------------------
      +       | DETB(JRUN,IKL) =RMAX(IKL,2)            |
      +       ------------------------------------------
      +                    |
      +
      +
      +
      +   ASPEC( ) = TARGET ASPECT AT DETECTION
      +
      +       ASPEC(JRUN,IKL)=RMAX(IKL,5)
      +
      +
      +
      +   CLCSB( ) = BEARING TO CLOSEST PART OF TARGET
      +
      +       CLCSB(JRUN,IKL)=RMAX(IKL,4)
      +
      +
      +
      +   DERB( ) = REL BEARING FROM MAIN TORP COURSE TO TARGET
      +
      +                    |
      +       ------------------------------------------
      +       | DERB(JRUN,IKL) =RMAX(IKL,6)            |
      +       ------------------------------------------
      +                    |
      +
  910 +++++++++CONTINUE
      +                    |
```

(CONTINUED ON PAGE 10)

```
+
+           |
+           |
+           |
+       . *   * .
+     . *   IF    * .
+   *    IFLAG.EQ.1     *
+   * .                 . *-------------------
+     * .           . *        T    | 991 |
+       * .   . *                   -------
+           |
+           F
+           |
+           |
+
+
+
+
+   PRINT OUT (STEP 10)
+
+             |
+    ---------------------------------------------
+    | COUR =MCOURS/RAD                          |
+    | TC   =TCCURS/RAD                          |
+    | IT   =ITIME/2                             |
+    ---------------------------------------------
+             |
+             |
+             |
+       . *   * .
+     . *   IF    * .
+   *    IPRINT.EQ.0    *
+   * .                 . *-------------------
+     * .           . *        T    | 195 |
+       * .   . *                   -------
+           |
+           F
+           |
+           |
+
+     ***WRITE(6,232)JRUN,TACMG,TAM1,ENGMOD,DA1,COUR,XT,YT,XTAR,YTAR,
+        IT,MXT
+
232 +        FORMAT(1X,/,1X,I3,3X,F5.1,2X,F4.1,1X,F6.0,2X,F5.1,3X,
+        F5.1,7X,F6.0,1X,F6.0,2X,F6.0,1X,F6.0,3X,I4,2X,F6.0)
+           |
+       . *   * .
+     . *   IF    * .
+   *   RMAX(1,1).EQ.0.   *
+   * .                 . *-------------------
+     * .           . *        T    | 991 |
+       * .   . *                   -------
+           |
+           F
+           |
+           |
+           |
+       -------
+       | 900 |
+       -------
+
+
+
+
195 +     ***WRITE(6,200)IT
+
200 +        FORMAT(1X,'RUN STOPPED AFTER ',I5,' SECONDS',//,
+        1X,'RUN DATA AS FOLLOWS AT END OF RUN')
+           |
```

(CONTINUED ON PAGE 11)

```
     +
     +                 |
     +
     +     ***WRITE(6,202) SXT,DIST
     +
 202 +        FORMAT(1X,'TOTAL TORP RUN ',F9.1,/,1X,'DIST TO TARGET ',F9.1)
     +
     +     ***WRITE(6,204) XT,YT,XTAR,YTAR,COUR,TC
     +
 204 +        FORMAT(1X,'TORP X-COORD ',2X,F9.1,4X,'TORP Y-COORD ',2X,F9.1,/,
     +        1X,'TARGET X-CCORD ',F9.1,4X,'TARGET Y-COORD ',F9.1,/,
     +        1X,'TORP MAIN COURSE ',F9.3,6X,'TORP COURSE ',1X,F9.3)
     +                 |
     +                 |
     +             . *   * .
     +         . *     IF     * .
     +      *  RMAX(1,1).EQ.0.  *
     +      * .                . *-------------------
     +          * .         . *         T     | 991  |
     +              *  .  *                   --------
     +                 |
     +                 F
     +                 |
     +                 |
     +
     +     ***WRITE(6,206)
     +
     +     ***WRITE(6,208) (I,(RMAX(I,J),J=1,5),I=1,5)
     +
 206 +        FORMAT(1X,/,1X,'MAXIMUM DETECTION RANGES AND BEARINGS',
     +        /,1X,'SUCCESSIVE',4X,'MAX  DET',9X,'DET BEARING',
     +        5X,'MAX  DET',11X,'DET BEARING',4X,'TARGET',/,
     +        1X,'DET     NC.',4X,'RANGE - CENTER',4X,
     +        'CENTER',9X,'RANGE - CLOSEST',4X,'CLOSEST',
     +        8X,'ASPECT')
     +
 208 +        FORMAT(3X,I4,7X,F10.1,7X,F8.2,7X,F10.1,9X,
     +        F8.2,7X,F8.2)
     +                 |
     +              -------
     +              | 900 |
     +              -------
     +
     +
     +
     +
 991 +     ***WRITE(6,220)
     +
     +
     +
     +
     +    ALL RUN COMPLETED ? (STEP 11)
     +
     +
 900 +++++++++CONTINUE


          CALCULATE SUMMARY RESULT (STEP 12)
                       |
               +-------+-------+
              + DO             +
 ++++++++++        27           +
     +        + KR=1,5          +
     +         +-------+-------+
     +                 |
     +                 |
```

(CONTINUED ON PAGE 12)

```
      +
      +              |
      +              |
      +        +-------------+
      +       + DO            +
      ++++++++++     28         +
      +       + LR=1,IRUN     +
      +        +-------------+
      +              |
      +              |
      +     ----------------------------------------------
      +     | BM(KR,1)  =BM(KR,1)+FLOAT(KON(LR,KR))     |
      +     | BM(KR,2)  =BM(KR,2)+DET(LR,KR)            |
      +     | BM(KR,3)  =BM(KR,3)+ABS(ASPEC(LR,KR))     |
      +     | BM(KR,4)  =BM(KR,4)+DETS(LR,KR)           |
      +     | BM(KR,5)  =BM(KR,5)+DERB(LR,KR)           |
      +     ----------------------------------------------
      +              |
      +
   28 ++++++++CONTINUE
      +
   27 ++++++++CONTINUE
                     |
               +-------------+
              + DO            +
      ++++++++++     920        +
      +       + KK=1,5        +
      +        +-------------+
      +              |
      +
      +
      +
      +
      +    COMPUTING MEANS
      +
      +              |
      +     ----------------------------------------------
      +     | DEL   =BM(KK,1)                           |
      +     ----------------------------------------------
      +              |
      +              |
      +              |
      +          . *   * .
      +      . *     IF     * .
      +    *      DEL.LE.1.      *
      +    * .                 . *-----------------------------------
      +      * .             . *          T    | DEL=1.
      +          * .   . *                     -------------------------
      +              |                              |
      +              F                              |
      +              |-------------------------------
      +              |
      +              |
      +     ----------------------------------------------
      +     | BM(KK,2)  =BM(KK,2)/DEL                   |
      +     | BM(KK,3)  =BM(KK,3)/DEL                   |
      +     | BM(KK,4)  =BM(KK,4)/DEL                   |
      +     | BM(KK,5)  =BM(KK,5)/DEL                   |
      +     ----------------------------------------------
      +              |
      +
  920 ++++++++CONTINUE
```

(CONTINUED ON PAGE 13)

```
                      |
              +-------------+
             + DO            +
++++++++++          25         +
+            + KK=1,5        +
+             +-------------+
+                     |
+                     |
+          ----------------------------------------
+          | VAR(KK)  =0.                          |
+          ----------------------------------------
+                     |
+                     |
+              +-------------+
+             + DO            +
++++++++++         170         +
+            + I=1,IRUN      +
+             +-------------+
+                     |
+                     |
+                 . *   * .
+             . *    IF    * .
+          *  KCN(I,KK).EQ.0   *
+          * .               . *-------------------
+             * .         . *        T     | 170 |
+                 * . *               -------
+                     |
+                     F
+                     |
+                     |
+          ----------------------------------------
+          | VAR(KK)  =VAR(KK)+((DET(I,KK)-RM(KK,2))|
+          |       **2)                            |
+          ----------------------------------------
+                     |
+
170 ++++++++CONTINUE
+
25 ++++++++CONTINUE
                      |
              +-------------+
             + DO            +
++++++++++          26         +
+            + KR=1,5        +
+             +-------------+
+                     |
+                     |
+          ----------------------------------------
+          | DEL   =RM(KR,1)                       |
+          ----------------------------------------
+                     |
+                     |
+                 . *   * .
+             . *    IF    * .
+          *     DEL.LE.2.     *
+          * .               . *--------------------------------
+             * .         . *        T     | DEL=2.
+                 * . *               ---------------------------
+                     |                          |
+                     F                          |
+                     |---------------------------
+                     |
+                     |
+          ----------------------------------------
+          | STD(KR)  =SQRT(VAR(KR)/(DEL-1.))      |
+          | RM(KR,1)  =RM(KR,1)/FLOAT(IRUN)       |
+          ----------------------------------------
+                     |
+
```

(CONTINUED ON PAGE 14)

```
     +
     +                    |
     +
     ++++++++CONTINUE



        PRINT SUMMARY (STEP 13)

         ***WRITE(6,197)JRUN

 197        FORMAT(1X,//,6X,'SUMMARY OF RESULT AFTER',3X,I4,2X,'RUNS')

         ***WRITE(6,199) ((RM(I,J),J=1,2),STD(I),(RM(I,J),J=3,5),I=1,5)

 199        FORMAT(10X,'PROBABILITY OF DETECTION',8X,
            'AVERAGE',6X,'STD DEVIATION',7X,'AVERAGE',7X,'AVERAGE',
            7X,'AVERAGE',/,41X,
            'DET RANGE',6X,'DET RANGE',7X,'TARGET ASPECT',4X,'DET BEARING',
            3X,'REL BEARING',/,
            1X,'ONE SUCCESSIVE DETECTION',5X,F6.4,5(6X,F9.4),/,
            1X,'TWO SUCCESSIVE DETECTIONS',4X,F6.4,5(6X,F9.4),/,
            1X,'THREE SUCCESSIVE DETECTIONS',2X,F6.4,5(6X,F9.4),/,
            1X,'FOUR SUCCESSIVE DETECTIONS',3X,F6.4,5(6X,F9.4),/,
            1X,'FIVE SUCCESSIVE DETECTIONS',3X,F6.4,5(6X,F9.4),/)

 220        FORMAT(1X,'NO DETECTION MADE DURING THIS RUN')
                  |
            ----------------------------------------------
            | DA2  =DA2/FLOAT(IRUN)                       |
            ----------------------------------------------
                  |
         ***WRITE(6,190)DA2

 190        FORMAT(1X,/,1X,'AVERAGE DEFLECTION ANGLE :',5X,F8.4,/)

         ***WRITE(6,234)

 234        FORMAT(1X,/,1X,'DISTRIBUTION OF RUN RESULT - CENTER OF TARGET',/,
            6X,'ONE SUCCESSIVE DETECTION',10X,'TWO SUCCESSIVE DETECTIONS',
            8X,'THREE SUCCESSIVE DETECTIONS',/,
            2X,'BEAR',2X,'RANGE  ASPECT BEAR CLOS',6X,'BEAR',2X,
            'RANGE  ASPECT BEAR CLOS',5X,'BEAR',2X,
            'RANGE  ASPECT BEAR CLOS')


         ***WRITE(6,236)((DETB(I,1),DET(I,1),ASPEC(I,1),CLOSB(I,1),
            DETB(I,2),DET(I,2),ASPEC(I,2),CLOSB(I,2),DETB(I,3),
            DET(I,3),ASPEC(I,3),CLOSB(I,3)),I=1,IRUN)

 236        FORMAT(3(1X,F6.1,1X,F6.1,1X,F6.1,2X,F6.1,5X))

 999        STOP

END
```

```
A TORPEDO SIMULATION.    SUBROUTINE PARMET.

    SUBROUTINE PARMET
READING IN DATA AND PARAMETERS

    COMMON ISEED2, TTIME, TO, TA, TRATE, RANGE, ALPA, LAMBD, TADEC,
    BEAR, RAD, TAC, CCOR, DEVSP, BNG, EN, PH2, MCCURS, TCOURS,
    MXT, MXM, IK, IDTIME, ITIME, XT, YT, XTAR, YTAR, TDIST,
    MDIST, TURNTO, INTVAL, PHI, RMAX(5,6), TRANGE, DIST,IPRINT

    REAL LAMBD, MCOURS, MXT, MXM, MDIST, LAMBDG

    INTEGER RUNCUT


TEDEC - TECHNICAL DETECTION RANGE (STEP A1)

LEVEL OF VARIATION: 375-750-1125-1500 METERS

TADEC - TACTICAL DETECTION RANGE
              |
    ----------------------------------------
    | TEDEC=750.                           |
    | TADEC=TEDEC                          |
    ----------------------------------------
              |


TTIME - TRANSMISSION INTERVAL
              |
    ----------------------------------------
    | TTIME=2.*TEDEC/1500.                 |
    ----------------------------------------
              |


TOKN - TORP SPEED IN KNOTS, TO - TORP SPEED IN M/SEC (STEP A2)

LEVEL OF VARIATION: 24-32-40 KNOTS
              |
    ----------------------------------------
    | TOKN =40.                            |
    | TO   =TOKN/2                         |
    ----------------------------------------
              |


TAKN - TARGET SPEED IN KNOTS, TA - TARGET SPEED IN M/SEC (STEP A3)

LEVEL OF VARIATION: 12-18-24-30 KNOTS
              |
    ----------------------------------------
    | TAKN =18.                            |
    | TA   =TAKN/2                         |
    ----------------------------------------
              |
```

(CONTINUED ON PAGE   2)

```
                    |

TACG - TARGET COURSE IN DEGREE (STEP A4)
                    |
     ---------------------------------------------
     | TACG =270                                 |
     | TAC  =TACG*RAD                            |
     ---------------------------------------------
                    |

ALFAG - SWEEP ANGLE IN DEGREE, ALFA - SWEEP ANGLE IN RADIANS

              (STEP A5)

LEVEL OF VARIATION: 20-30-40 DEGREES
                    |
     ---------------------------------------------
     | ALFAG=30.                                 |
     | ALFA =ALFAG*RAD                           |
     ---------------------------------------------
                    |

LAMBDG - LOBE WIDTH EACH SIDE OF TORP HEADING (STEP A6)

LEVEL OF VARIATION: 10-20-30 DEGREES
                    |
     ---------------------------------------------
     | LAMBDG =20.                               |
     | LAMBD=LAMBDG*RAD                          |
     ---------------------------------------------
                    |

BELBRG - RELATIVE BEARING FROM TARGET TO TORP IN DEGREE (STEP A7)

LEVEL OF VARIATION: 0-30-60-90-120-180 DEGREES
                    |
     ---------------------------------------------
     | BELBRG =-60.                              |
     | BEAR =BELBRG*RAD                          |
     ---------------------------------------------
                    |

RANGE - DISTANCE BETWEEN TARGET AND TORP (STEP A8)

LEVEL OF VARIATION: 1500-3000-5000-7000 METERS
                    |
     ---------------------------------------------
     | RANGE=3000.                               |
     ---------------------------------------------
                    |
```

(CONTINUED ON PAGE 3)

```
                  |

        TRANGE - MAX TORP RUN IN METERS (STEP A9)
                  |
            -----------------------------------------
            | TRANGE =18000.                        |
            -----------------------------------------
                  |

        TRATEG - TORP TURNRATE IN DEGREE PER SEC (STEP A10)

        LEVEL OF VARIATION: 3-6-9-12-15-18-21 DEGREE/SEC
                  |
            -----------------------------------------
            | TRATEG =18.                           |
            | TRATE=TRATEG*RAD                      |
            -----------------------------------------
                  |

        CALCULATE WIDTH OF TACTICAL SWEEP-LANE (THEORETICAL)
                  |
            -----------------------------------------
            | SWNG =TADEC*SIN(ALFA+LAMBD)*2.        |
            -----------------------------------------
                  |

        CALCULATE COVERAGE RATIO (THEORETICAL)
                  |
            -----------------------------------------
            | CRATIO =1.-(TRATE*TTIME/(2.*LAMBD))   |
            -----------------------------------------
                  |

        PRINT OF SITUATION AT START OF RUN (STEP A12)
                  |
                  |
              . *   * .
          . *    IF     * .
        *   IPRINT.EQ.0     *
        * .               . *------------------
          * .           . *        T    | 90  |
              * .   . *                 -------
                  |
                  F
                  |
                  |
         ***WRITE(6,110)
110         FORMAT(1X,//,1X,'TACTICAL SITUATION WHEN FIRING',6X,
            'TORPEDO PARAMETER',/,
            2X,'RANGE  ATTACK  TARGET  TARGET',6X,'TEC.DET  TORP',
            3X,'SWEEP  LOBE   TURN  SWEEP  COVERAGE',//,
            9X,'ANGLE   COURSE  SPEED',7X,'RANGE    SPEED',2X,
            'ANGLE  WIDTH  RATE  LANE',4X,'RATIO')
                  |
```

(CONTINUED ON PAGE 4)

```
                  |
         ***WRITE(6,112)RANGE,RELBRG,TACG,TAKN,TEDEC,TOKN,ALFAG,
            LAMBDG,TRATEG,SRNG,CRATIO
 112        FORMAT(1X,F6.0,2X,F6.1,3X,F5.1,3X,F4.1,6X,F6.1,3X,F5.1,3X,
            F4.1,3X,F4.1,2X,F4.1,2X,F6.1,3X,F5.3)
                  |
               -------
               | 95  |
               -------

  90     ***WRITE(6,100)
 100        FORMAT(1X,'TACTICAL SITUATION WHEN FIRING',/,1X,
            'FIRING RANGE',3X,'ATTACK ANGLE',3X,
            'TARGET COURSE',2X,'TARGET SPEED')
         ***WRITE(6,102)RANGE,RELBRG,TACG,TAKN
 102        FORMAT(1X,4(2X,F6.1,7X),/)
         ***WRITE(6,104)
 104        FORMAT(1X,'TORPEDO PARAMETERS',/,1X,
            'TECH.DET.RANGE',2X,'TRANS.INT.VAL',2X,'TORP SPEED',3X,
            'SWEEP ANGLE')
         ***WRITE(6,106)TEDEC,TTIME,TOKN,ALFAG
 106        FORMAT(1X,2(2X,F7.2,7X),2(F6.1,7X),/)
         ***WRITE(6,108)LAMBDG,TRATEG
 108        FORMAT(1X,'LOBE WIDTH',6X,'TURN RATE',/,
            3X,F6.1,10X,F6.1)
         ***WRITE(6,109)SRNG,CRATIO
 109        FORMAT(1X,'THEORETICAL WIDTH OF TACTICAL SWEEP-LANE',F9.1,
            /,1X,'THEORETICAL COVERAGE RATIO',F9.4)
  95        RETURN
END
```

A TORPEDO SIMULATION.   SUBROUTINE FIRING.

```
    SUBROUTINE FIRING
CALCULATE THE TORP DEFLECTION ANGLE, MAIN COURSE, FIRING COURSE

BASED ON ESTIMATE OF TARGET DATA (UNCERTAINTY)


    DIMENSION U(2)
    COMMON ISEED2, TTIME, TO, TA, TRATE, RANGE, ALFA,LAMBD,TADEC,
    BEAR, RAD, TAC, CCOR, DEVSP, BNG, EN, PH2, MCOURS, TCOURS,
    MXT, MXM, IK, IDTIME, ITIME, XT, YT, XTAR, YTAR, TDIST,
    MDIST, TURNTC, INTVAL, PHI, BMAX(5,6), TRANGE, DIST,IPRINT
    COMMON/DATA/IA,OFLOB
    COMMON/TARGET/TACMG,TAM1,RNGMOD,DA1,COUR,CZ(10),SZ(15),JRUN,
    IFLAG,DA2
    REAL LAMBD, MCOURS, MXT, MXM, MDIST, LAMBDG
    INTEGER RUNOUT

    -------------------------------------------
    | EN     =-1                              |
    | EP     =1.                              |
    | KSPEED =MOD((JRUN-1),15)+1              |
    | KCOURS =IFIX((JRUN-1)/15.)+1            |
    -------------------------------------------

    CALL GGUE(ISEED2,2,U)


CALCULATE ESTIMATE OF TARGET COURSE (STEP 31)

    -------------------------------------------
19  | TACM =TAC+CZ(KCOURS)                    |
    -------------------------------------------
    -------------------------------------------
20  | DIFCO=TACM-TAC                          |
    -------------------------------------------
```

(CONTINUED ON PAGE   2)

```
                  |
                  |
            . *   *  .
        . *    IF       * .
      *   TACM.GE.PH2      *
      * .                .  *-------------------------------------
        * .             . *          T      | TACM=TACM-PH2
            *    .   *                    ---------------------------
                 |                                 |
                 F                                 |
                 |---------------------------------
                 |
                 |
                 |
            . *   *  .
        . *    IF       * .
      *   TACM.LT.0.       *
      * .                .  *-------------------------------------
        * .             . *          T      | TACM=PH2+TACM
            *    .   *                    ---------------------------
                 |                                 |
                 F                                 |
                 |---------------------------------
                 |


   CALCULATE EST OF TARGET SPEED (STEP B2)
                 |
      -------------------------------------------
      | TAM   =TA+SE(KSPEED)                     |
      -------------------------------------------
                 |


   CALCULATE TORPEDO DEFLECTION ANGLE (STEP B3)
                 |
      -------------------------------------------
      | ASP   =BEAR-DIFCO                        |
      -------------------------------------------
                 |
                 |
                 |
            . *   *  .
        . *    IF       * .
      *   ASP.LT.-PHI      *
      * .                .  *-------------------------------------
        * .             . *          T      | ASP=PH2+ASP
            *    .   *                    ---------------------------
                 |                                 |
                 F                                 |
                 |---------------------------------
                 |
                 |
      -------------------------------------------
      | TACS =TAM*SIN(ABS(ASP))                  |
      | DAA  =TACS/TC                            |
      -------------------------------------------
                 |
```

(CONTINUED ON PAGE   3)

```
                         |
                         |
                     . * | * .
                 . *    IF     * .
               *     DAA.GE.1.      *
               * .                . *-------------------
                 * .            . *           T      | 26    |
                     * . * .                         --------
                         |
                         F
                         |
                         |
           ------------------------------------------------
           | DA    =ARSIN(DAA)                            |
           | DA    =SIGN(DA,ASP)                          |
           ------------------------------------------------
                         |


        CALCULATE TORPEDO MAIN FIRING COURSE (STEP B4)
                         |
           ------------------------------------------------
           | MCOURS =BNG+PHI+DA                           |
           ------------------------------------------------
                         |
                         |
10                   . * | * .
                 . *    IF     * .
               *   MCOURS.GT.PH2    *
               * .                . *-----------------------------------------
                 * .            . *           T      | MCOURS=MCOURS-PH2
                     * . * .                         -------------------------
                         |                                       |
                         F                                       |
                         |----------------------------------------
                         |
                         |
                     . * | * .
                 . *    IF     * .
               *   MCOURS.LT.0.     *
               * .                . *-----------------------------------------
                 * .            . *           T      | MCOURS=PH2+MCOURS
                     * . * .                         -------------------------
                         |                                       |
                         F                                       |
                         |----------------------------------------
                         |
                         |
                     . * | * .
                 . *    IF     * .
               *   MCOURS.GT.PH2    *
               * .                . *-------------------
                 * .            . *           T      | 10    |
                     * . * .                         --------
                         |
                         F
                         |
                         |
```

(CONTINUED ON PAGE   4)

```
                        |

     CALCULATE TORPEDO PRESENT FIRING COURSE (STEP 35)

                        |
      --------------------------------------------
      | DIFALF =(U(1)*2.*ALFA)-ALFA              |
      | TCOURS =HCOURS+DIFALF                    |
      --------------------------------------------
                        |
                        |
                  . *   * .
             . *    IF      * .
           *    TCOURS.GT.PH2   *
           * .                . *------------------------------------
              * .          . *          T     | TCOURS=TCOURS-PH2
                  * . *                        ---------------------
                        |                            |
                        F                            |
                        |-----------------------------
                        |
                        |
                  . *   * .
             . *    IF      * .
           *    TCOURS.LT.0.    *
           * .                . *------------------------------------
              * .          . *          T     | TCOURS=PH2+TCOURS
                  * . *                        ---------------------
                        |                            |
                        F                            |
                        |-----------------------------
                        |
                        |
                  . *   * .
             . *    IF      * .
           *    DIFALF.GE.0.    *
           * .                . *------------------------------------
              * .          . *          T     | PN=-PN
                  * . *                        ---------------------
                        |                            |
                        F                            |
                        |-----------------------------
                        |


     CALCULATE ESTIMATE OF TARGET RANGE (STEP 36)

                        |
                  . *   * .
             . *    IF      * .
           *     U(2).GE.0.5    *
           * .                . *------------------------------------
              * .          . *          T     | PP=-PP
                  * . *                        ---------------------
                        |                            |
                        F                            |
                        |-----------------------------
                        |
                        |
      --------------------------------------------
      | RNGDIF =(1.-U(2))*RANGE*0.15             |
      --------------------------------------------
                        |
```

(CONTINUED ON PAGE   5)

```
                |
          RNGMOD=RANGE+SIGN(RNGDIF,PP)
                |
          ----------------------------------------
          | TACMG=TACM/RAD                       |
          | TAM1 =TAM*2                          |
          | DA1  =DA/RAD                         |
          | DA2  =DA2+DA1                        |
          ----------------------------------------
                |


      PRINT OUT OF FIRING DATA

                |
            . *   * .
         . *   IF    *. .
        *   IPRINT.EQ.1    *
        * .              . *----------------
           .* .      . *          T    | 25  |
              * . *                    -------
                |
                F
                |
                |

       ***WRITE(6,122)TACMG,IAM1,RNGMOD
122       FORMAT(1X,'EST OF TARGET DATA FOR FIRING',/,
          4X,'COURSE',5X,'SPEED',6X,'RANGE',/,
          1X,3(F8.1,3X))
       ***WRITE(6,124)DA1
124       FORMAT(1X,'TORP DEFLECTION ANGLE IS   ',F6.2)
                |
          ----------------------------------------
          | COUR =MCCURS/RAD                     |
          ----------------------------------------
                |
       ***WRITE(6,125)COUR
125       FORMAT(1X,'TORPEDO MAIN COURSE',8X,F6.2)
126       CONTINUE
                |
              -------
              | 25  |
              -------


26     ***WRITE(6,30)
30        FORMAT(/,1X,'NOT FEASIBLE TO FIRE DUE TO LOW TORPEDO SPEED')
                |
          ----------------------------------------
          | IFLAG=1                              |
          ----------------------------------------
                |
25        RETURN

END
```

```
                 |
    A TORPEDO SIMULATION.   SUBROUTINE POSIS.

       SUBROUTINE POSIS
    IS CALCULATING NEW POSITIONS OF TARGET AND TORPEDO IN

    EACH TIME STEP


       COMMON ISEED2, TTIME, TO, TA, TRATE, RANGE, ALFA, LAMBD, TADEC,
       BEAR, RAD, TAC, COOR, DEVSP, BNG, EN, PH2, MCOURS, TCOURS,
       MXT, MXM, IK, IDTIME, ITIME, XT, YT, XTAR, YTAR, TDIST,
       MDIST, TURNTO, INTVAL, PHI, RMAX(5,6), TRANGE, DIST,IPRINT

       REAL LAMBD, MCOURS, MXT, MXM, MDIST, LAMBDG

       INTEGER RUNOUT


    TIME COUNT (STEP C1)
                 |
       ----------------------------------------
       | IK    =IK+1                          |
       | ITIME=ITIME+IDTIME                   |
       ----------------------------------------
                 |


    CALCULATE TOTAL TORP RUN  AND TARGET RUN (STEP C2)
                 |
       ----------------------------------------
       | MXT   =MXT+TDIST                     |
       | MXM   =MXM+MDIST                     |
       ----------------------------------------
                 |


    CALCULATE NEW POSITIONS (STEP C3)
                 |
       ----------------------------------------
       | XT    =XT+SIN(TCOURS)*TDIST          |
       | YT    =YT+COS(TCOURS)*TDIST          |
       | XTAR  =XTAR+SIN(TAC)*MDIST           |
       | YTAR  =YTAR+COS(TAC)*MDIST           |
       ----------------------------------------
                 |


    CALCULATE NEW TORP COURSE (STEP C4)
                 |
       ----------------------------------------
       | TXCOUR =TCOURS+SIGN(TURNTO,EN)       |
       | TXCDIF =ABS(MCOURS-TXCOUR)           |
       ----------------------------------------
                 |
                 |
```

(CONTINUED ON PAGE   2)

```
                    |
                    |
               . *     * .
           . *     IF      * .
         *   TXCDIF.GT.PHI   *
         * .               . *------------------------------------
              * .        . *         T     | TXCDIF=PH2-TXCDIF
                  *  .  *                  ------------------------
                    |                          |
                    F                          |
                    |---------------------------
                    |
                    |
               . *     * .
           . *     IF      * .
         *  TXCDIF.LE.ALFA   *
         * .               . *----------------
              * .        . *         T     | 15   |
                  *  .  *                  -------
                    |
                    F
                    |
                    |
     ----------------------------------------------
     | PN     =-PN                                |
     | ALFADI =TXCDIF-ALFA                        |
     | TXCOUR =TXCOUR+2.*SIGN(ALFADI,PN)          |
     ----------------------------------------------
                    |
     ----------------------------------------------
15   | TCOURS =TXCOUR                             |
     ----------------------------------------------
                    |
                    |
               . *     * .
           . *     IF      * .
         *   TCOURS.GT.PH2   *
         * .               . *------------------------------------
              * .        . *         T     | TCOURS=TCOURS-PH2
                  *  .  *                  ------------------------
                    |                          |
                    F                          |
                    |---------------------------
                    |
                    |
               . *     * .
           . *     IF      * .
         *   TCOURS.LT.0.    *
         * .               . *------------------------------------
              * .        . *         T     | TCOURS=PH2+TCOURS
                  *  .  *                  ------------------------
                    |                          |
                    F                          |
                    |---------------------------
                    |
25          RETURN

END
```

```
           A TORPEDO SIMULATION.   SUBROUTINE DETECT.

               SUBROUTINE DETECT
           TO CHECK IF TARGET IS DETECTED AND STORE DETECTION DATA


               COMMON ISPEC2, TTIME, TO, TA, TRATE, RANGE, ALFA, LAMBC, TADEC,
               SEAR, RAD, TAC, CCCR, DEVSP, BNG, EN, PH2, MCCURS, TCOURS,
               MXT, MXM, IK, IDTIME, ITIME, XT, YT, XTAR, YTAR, TDIST,
               MDIST, TURNTC, INTVAL, PHI, RMAX(5,6), TRANGE, DIST,IPRINT
               COMMON/DATA/DA,OPLCB
               REAL LAMBC, MCOURS, MXT, MXM, MDIST, LAMBDG
               INTEGER RUNOUT
               DIMENSION DB(3,2)
               DOUBLE PRECISION PCWMAX,B,RBX,RBX1,RBX2,X1,X2,X3,XX1,
               V1,V2,V,U,FIFACT,XO1,XO2,XO3,XX2,POWER,RELB,ALAM


           SETTING OF TARGET DIMENSION, A - TARGET LENGTH,


           B - TARGET WIDTH,C  - TARGET DEPTH. (STEP D1)
                          |
               -------------------------------------------
               | A     =100.                             |
               | B     =15.                              |
               | C     =4.                               |
               -------------------------------------------
                          |


           CHECK IF TRANSMISSION (STEP D2)
                          |
                          |
                   .  *   *  .
              .  *     IF     *  .
            *    IK.LT.INTVAL      *
            *  .                .  *-----------------------
                 *  .        .  *          T     | 20   |
                       *  .  *                    ------
                          |
                          F
                          |
                          |
                          |
               -------------------------------------------
               | IK    =0                                |
               -------------------------------------------
                          |
```

(CONTINUED ON PAGE 2)

```
                        |


        CALCULATE RANGE TO TARGET (STEP D3)
                        |
            -------------------------------------------
            | DIFX =XTAR-XT                            |
            | DIFY =YTAR-YT                            |
            | DIST =SQRT((DIFX**2)+(DIFY**2))          |
            -------------------------------------------
                        |


        TEST IF TARGET IS WITHIN POSSIBLE DETECTION RANGE

                        |
                  .  *     *  .
              . *       IF       * .
           *DIST.GT.(TADEC+A/2.)
           * .                     . *-----------------
               * .             . *          T     | 20  |
                    *  .  *                        -------
                        |
                        F
                        |


        DETECTION THRESHOLD (STEP D4)
                        |
            -------------------------------------------
            | POWMAX =1./(B*TADEC)**4                  |
            | U      =SCALE(PHI/2.)                    |
            | CONST=(A**2)*(B**2)*(C**2)               |
            | POWMAX =CONST*POWMAX*U                   |
            -------------------------------------------
                        |


        CALCULATE TIME TO TARGET (STEP D5)
                        |
            -------------------------------------------
            | TIMDL1 =DIST/1500.                       |
            | XTAR1=XTAR+SIN(TAC)*(TIMDL1*TA)          |
            | YTAR1=YTAR+COS(TAC)*(TIMDL1*TA)          |
            -------------------------------------------
                        |


        CENTB - BEARING OF CENTER OF LOBE (STEP D6)
                        |
            -------------------------------------------
            | DD    =-DA*CFLOB                         |
            | CENTB=TCOUBS+DD                          |
            -------------------------------------------
                        |
```

(CONTINUED ON PAGE   3)

```
                   |
                   |
              . *  |  * .
          . *     IF      * .
        *     CENTB.LT.0.      *
        * .                  . *--------------------------------------
            * .          . *             T      | CENTB=PH2+CENTB
                *  .  *                         ----------------------
                   |                                     |
                   F                                     |
                   |--------------------------------------
                   |
                   |
              . *  |  * .
          . *     IF      * .
        *     CENTB.GT.PH2     *
        * .                  . *--------------------------------------
            * .          . *             T      | CENTB=CENTB-PH2
                *  .  *                         ----------------------
                   |                                     |
                   F                                     |
                   |--------------------------------------
                   |


       CALCULATE BEARINGS TO TARGET (STEP D7)
                   |
        --------------------------------------------------
        | RB    =BEARIN(XTAR1,YTAR1,XT,YT)               |
        | XTAR2=XTAR1+SIN(TAC)*A/2.                      |
        | YTAR2=YTAR1+COS(TAC)*A/2.                      |
        | DIST1=SQRT((XTAR2-XT)**2+(YTAR2                |
        |       -YT)**2)                                 |
        | RB1   =BEARIN(XTAR2,YTAR2,XT,YT)               |
        | XTAR3=XTAR1-SIN(TAC)*A/2.                      |
        | YTAR3=YTAR1-COS(TAC)*A/2.                      |
        | DIST2=SQRT((XTAR3-XT)**2+(YTAR3                |
        |       -YT)**2)                                 |
        | RB2   =BEARIN(XTAR3,YTAR3,XT,YT)               |
        | REL1 =RB1-CENTB                                |
        --------------------------------------------------
                   |
                   |
                   |
              . *  |  * .
          . *     IF      * .
        *     REL1.GT.PHI      *
        * .                  . *--------------------------------------
            * .          . *             T      | REL1=REL1-PH2
                *  .  *                         ----------------------
                   |                                     |
                   F                                     |
                   |--------------------------------------
                   |
                   |
```

(CONTINUED ON PAGE   4)

```
                  |
                  |
            . *   |  * .
         . *     IF       * .
        *   REL1.LT.-PHI     *
        * .                . *------------------------------------------
            * .         . *            T     | REL1=PH2+REL1
                 *  .  *                     ----------------------------
                    |                              |
                    F                              |
                    |-------------------------------
                    |
                    |
      ---------------------------------------------
      | RELO =RE-CENTB                            |
      ---------------------------------------------
                    |
                    |
            . *   |  * .
         . *     IF       * .
        *    RELO.GT.PHI     *
        * .                . *------------------------------------------
            * .         . *            T     | RELO=RELO-PH2
                 *  .  *                     ----------------------------
                    |                              |
                    F                              |
                    |-------------------------------
                    |
                    |
            . *   |  * .
         . *     IF       * .
        *   RELO.LT.-PHI     *
        * .                . *------------------------------------------
            * .         . *            T     | RELO=PH2+RELO
                 *  .  *                     ----------------------------
                    |                              |
                    F                              |
                    |-------------------------------
                    |
                    |
      ---------------------------------------------
      | REL2 =RE2-CENTB                           |
      ---------------------------------------------
                    |
                    |
            . *   |  * .
         . *     IF       * .
        *    REL2.GT.PHI     *
        * .                . *------------------------------------------
            * .         . *            T     | REL2=REL2-PH2
                 *  .  *                     ----------------------------
                    |                              |
                    F                              |
                    |-------------------------------
                    |
```

(CONTINUED ON PAGE   5)

```
                  |
                  |
            . *   |   * .
        . *      IF       * .
      *    REL2.LT.-PHI       *
      * .                     . *------------------------------------
        * .               . *          T    | RELO=PH2+REL2
            * .       . *                   -------------------------
                  |                                  |
                  F                                  |
                  |-----------------------------------
                  |


    CALCULATE TRANSMISSION GAIN FACTOR (STEP D8)

                  |
     ---------------------------------------------
     | RBX1  =REL1                               |
     | RBX   =RELO                               |
     | RBX2  =REL2                               |
     | ALAM  =LAMBD                              |
     ---------------------------------------------
                  |


    COMPUTE SEPARATE GAIN FACTORS (STEP D9)

                  |
     ---------------------------------------------
     | X1     =XFACT(RBX1,ALAM)                  |
     | X2     =XFACT(RBX,ALAM)                   |
     | X3     =XFACT(RBX2,ALAM)                  |
     | XX1    =(X1+X2+X3)/3.                     |
     ---------------------------------------------
                  |


    CALCULATE TARGET ASPECT AND TARGET SONAR CROSS-

    AREA (TARGET STRENGTH) DUE TO ASPECT (STEP D10)

                  |
     ---------------------------------------------
     | ANTRB=BE+PHI                              |
     ---------------------------------------------
                  |
                  |
            . *   |   * .
        . *      IF       * .
      *    ANTRB.GT.PH2       *
      * .                     . *------------------------------------
        * .               . *          T    | ANTRB=ANTRB-PH2
            * .       . *                   -------------------------
                  |                                  |
                  F                                  |
                  |-----------------------------------
                  |
     ---------------------------------------------
     | BELA  =ANTRB-TAC                          |
     ---------------------------------------------
                  |
```

(CONTINUED ON PAGE   6)

```
                    |
                . *   * .
            . *    IF     * .
          *   RELA.GT.PHI     *
          * .                 . *-------------------------------------------
              * .         . *           T      | RELA=PH2-RELA
                  * . *                        ----------------------------
                    |                                  |
                    F                                  |
                    |-----------------------------------
                    |
                    |
                . *   * .
            . *    IF     * .
          *   RELA.LT.-PHI    *
          * .                 . *-------------------------------------------
              * .         . *           T      | RELA=PH2+RELA
                  * . *                        ----------------------------
                    |                                  |
                    F                                  |
                    |-----------------------------------
                    |
         ------------------------------------------------------
         | RELB =ABS(RELA)                                    |
         | V1   =(A**2)*(DCOS(RELB)**2)                       |
         | V2   =(B**2)*(DSIN(RELB)**2)                       |
         | V    =(V1+V2)**2                                   |
         ------------------------------------------------------
                    |


     COMPUTE SCALING FACTOR DUE TO ASPECT (STEP D11)
                    |
         ------------------------------------------------------
         | U      =SCALE(RELB)                                |
         | FIPACT =U/V                                        |
         ------------------------------------------------------
                    |


     CALCULATE RETURNTIME FOR ECHO (STEP D12)
                    |
         ------------------------------------------------------
         | TIMDL2 =2.*TIMDL1                                  |
         ------------------------------------------------------
                    |


     CALCULATE REL BEARING FOR RETURNING ECHO (STEP D13)
                    |
         ------------------------------------------------------
         | TURNST =TRATE*TIMDL2                               |
         | TXC    =TCOURS+SIGN(TURNST,PN)                     |
         | TXDC   =ABS(MCOURS-TXC)                            |
         ------------------------------------------------------
                    |
```

(CONTINUED ON PAGE   7)

```
                         |
                         |
                  .  *   *  .
              . *     IF      * .
            *    TXDC.GT.PHI     *
            * .                . *---------------------------------
                *  .      .  *         T     | TXDC=PH2-TXDC
                     *  .  *                 ---------------------------
                        |                           |
                        F                           |
                        |----------------------------
                        |
                        |
                  .  *   *  .
              . *     IF      * .
            *    TXDC.LE.ALFA    *
            * .                . *----------------
                *  .      .  *         T     | 18  |
                     *  .  *                 -------
                        |
                        F
                        |
                        |
      -------------------------------------------------
      | ALF  =TXDC-ALFA                               |
      | RELTO=RELO-SIGN((TURNST-ALF),PN)              |
      |      +SIGN(ALF,PN)                            |
      -------------------------------------------------
                        |
                    ---------
                    | 19    |
                    ---------


                        |
      -------------------------------------------------
18    | RELTO=RELO-SIGN(TURNST,PN)                    |
      -------------------------------------------------
                        |
      -------------------------------------------------
19    | RELDIF =RELTO-RELO                            |
      | RELT1=REL1+RELDIF                             |
      | RELT2=REL2+RELDIF                             |
      -------------------------------------------------
                        |
                        |
                  .  *   *  .
              . *     IF      * .
            *    RELTO.GT.PHI    *
            * .                . *---------------------------------
                *  .      .  *         T     | RELTO=PH2-RELTO
                     *  .  *                 ---------------------------
                        |                           |
                        F                           |
                        |----------------------------
                        |
```

(CONTINUED ON PAGE   8)

```
                     |
               . *   |   * .
          . *     IF       * .
        *    RELT0.LT.-PHI    *
        * .                 . *-----------------------------------
             * .         . *          T     | RELT0=PH2+RELT0
                 *   .   *                  ----------------------------
                     |                                  |
                     F                                  |
                     |----------------------------------
                     |
                     |
               . *   |   * .
          . *     IF       * .
        *    RELT1.GT.PHI     *
        * .                 . *-----------------------------------
             * .         . *          T     | RELT1=PH2-RELT1
                 *   .   *                  ----------------------------
                     |                                  |
                     F                                  |
                     |----------------------------------
                     |
                     |
               . *   |   * .
          . *     IF       * .
        *    RELT1.LT.-PHI    *
        * .                 . *-----------------------------------
             * .         . *          T     | RELT1=PH2+RELT1
                 *   .   *                  ----------------------------
                     |                                  |
                     F                                  |
                     |----------------------------------
                     |
                     |
               . *   |   * .
          . *     IF       * .
        *    RELT2.GT.PHI     *
        * .                 . *-----------------------------------
             * .         . *          T     | RELT2=PH2-RELT2
                 *   .   *                  ----------------------------
                     |                                  |
                     F                                  |
                     |----------------------------------
                     |
                     |
               . *   |   * .
          . *     IF       * .
        *    RELT2.LT.-PHI    *
        * .                 . *-----------------------------------
             * .         . *          T     | RELT2=PH2+RELT2
                 *   .   *                  ----------------------------
                     |                                  |
                     F                                  |
                     |----------------------------------
                     |
```

(CONTINUED ON PAGE   9)

```
                      |
         TEST FOR DOPPLER

                      |
           ----------------------------------------
           | FRQDEF =50.*2.*(TO*COS(DD)-1.)        |
           |        /1500.                         |
           | FRQDIF =50.*2.*(TO*COS(DD)+1.)        |
           |        /1500.                         |
           | RELC =RELB                            |
           | FRQSH=50.*2.*(TO*COS(DD)+TA*COS(RELC))|
           |        /1500.                         |
           ----------------------------------------
                      |
                      |
                 . *  |  * .
              . *    IF    * .
           *(FRQSH.LT.FRQDIF) .AND. (FRQSH.GT.FRQDEF)
           * .                   . *-------------------
              * .            . *          T      | 20    |
                 *    .    *                     -------
                      |
                      F
                      |
                      |


         CALCULATE RANGE AND BEARING TO CLOSEST PART OF TARGET (STEP D14)
                      |
           ----------------------------------------
           | DB(1,1)  =DIST                        |
           | DB(1,2)  =RELT0+DD                    |
           | DB(2,1)  =DIST1                       |
           | DB(2,2)  =RELT1+DD                    |
           | DB(3,1)  =DIST2                       |
           | DB(3,2)  =RELT2+DD                    |
           | DMIN   =DB(1,1)                       |
           | MD     =1                             |
           ----------------------------------------
                      |
                      |
                 . *  |  * .
              . *    IF    * .
           *  DMIN.GT.DB(2,1)  *
           * .               . *-------------------
              * .          . *          T      | 10    |
                 *    .    *                   -------
                      |
                      F
                      |
                      |
 9               . *  |  * .
              . *    IF    * .
           *  DMIN.GT.DB(3,1)  *
           * .               . *-------------------
              * .          . *          T      | 11    |
                 *    .    *                   -------
                      |
                      F
                      |
                      |
```

(CONTINUED ON PAGE   10)

```
                    |
                    |
                 -------
                 | 12  |
                 -------


                    |
          ---------------------------------------------
10        | DMIN =DE(2,1)                              |
          | MD   =2                                    |
          ---------------------------------------------
                    |
                    |
                 -------
                 | 9   |
                 -------


                    |
          ---------------------------------------------
11        | DMIN =DE(3,1)                              |
          | MD   =3                                    |
          ---------------------------------------------
                    |
          ---------------------------------------------
12        | BREL =DE(MD,2)                             |
          ---------------------------------------------
                    |
                    |
                    |
            . *     *  .
       . *     IF       * .
     *    BREL.GT.PHI        *
     * .                  .  *-----------------------------------
         * .          . *          T    | BREL=PH2-BREL
             *  .  *                    -----------------------------
                    |                              |
                    F                              |
                    |-------------------------------
                    |
                    |
                    |
            . *     *  .
       . *     IF       * .
     *    BREL.LT.-PHI       *
     * .                  .  *-----------------------------------
         * .          . *          T    | BREL=PH2+BREL
             *  .  *                    -----------------------------
                    |                              |
                    F                              |
                    |-------------------------------
                    |


     CALCULATE RECEIVING GAIN FACTOR (STEP D15)
                    |
          ---------------------------------------------
          | RBX1 =RELT1                                |
          | RBX  =RELTC                                |
          | RBX2 =RELT2                                |
          | X01  =XFACT(RBX1,ALAM)                     |
          | X02  =XFACT(RBX,ALAM)                      |
          | X03  =XFACT(RBX2,ALAM)                     |
          | XX2  =(X01+X02+X03)/3.                     |
          ---------------------------------------------
                    |
```

(CONTINUED ON PAGE 11)

```
                       |

     CALCULATE FRACTION OF POWER IN TO RECIEVER (STEP D16)
                       |
        -------------------------------------------
        | POWER=CONST*XX1*XX2*FIPACT/(DIST        |
        |        **4)                             |
        -------------------------------------------
                       |

     TEST FOR DETECTION THRESHOLD (STEP D17)
                       |
                 . *   |   * .
            . *        IF       * .
          *   POWER.LT.POWMAX      *
          * .                    . *-------------------------
              * .            . *         T      | 15   |
                   *   .   *                    --------
                       |
                       F
                       |

     COMPUTE BEARING RATE (STEP D18)
                       |
        -------------------------------------------
        | ASP   =BE+PHI-TAC                       |
        -------------------------------------------
                       |
                       |
                 . *       * .
            . *        IF       * .
          *     ASP.GT.PHI         *
          * .                    . *------------------------------------
              * .            . *         T      | ASP=ASP-PH2
                   *   .   *                    ------------------------
                       |                              |
                       F                              |
                       |-------------------------------
                       |
                       |
                 . *       * .
            . *        IF       * .
          *     ASP.LT.-PHI        *
          * .                    . *------------------------------------
              * .            . *         T      | ASP=PH2+ASP
                   *   .   *                    ------------------------
                       |                              |
                       F                              |
                       |-------------------------------
                       |
        -------------------------------------------
        | AP    =ASP*BELTO                        |
        -------------------------------------------
                       |
```

(CONTINUED ON PAGE 12)

```
           TACS=TA*SIN(ABS(ASP))
                      |
           ------------------------------------------
           | TOCS  =TC*SIN(ABS(RELTO))               |
           | BRATE=(TACS+SIGN(TOCS,AP))/DIST         |
           ------------------------------------------
                      |


       CHECK BEARING RATE AGAINST TURNRATE (STEP D19)

                      |
                 . *     * .
             . *     IF      * .
           *   BRATE.GE.TRATE    *
           * .                 . *-------------------
               * .         . *          T      | 15   |
                   *  .  *                     -------
                      |
                      F
                      |



       CHECK TORPEDO SPEED ADVANTAGE (STEP D20)

                      |
           ------------------------------------------
           | TALS  =TA*COS(ABS(ASP))                 |
           | TOLS  =TC*COS(ABS(RELTO))               |
           ------------------------------------------
                      |
                      |
                 . *     * .
             . *     IF      * .
           *ABS(ASP).GT.PHI/2.   *
           * .                 . *---------------------------------
               * .         . *          T      | TALS=-TALS
                   *  .  *                     ---------------------
                      |                               |
                      F                               |
                      |-------------------------------
                      |
                      |
                 . *     * .
             . *     IF      * .
           *ABS(RELTO).GT.PHI/2.
           * .                 . *---------------------------------
               * .         . *          T      | TOLS=-TOLS
                   *  .  *                     ---------------------
                      |                               |
                      F                               |
                      |-------------------------------
                      |
```

(CONTINUED ON PAGE 13)

```
                     |
                 . * | * .
            . *     IF      * .
          *  (IALS+TCIS).LE.0.  *
          * .                  . *------------------
            * .                . *       T     | 15    |
                 * . *                          --------
                     |
                     F
                     |


                     |
      ---------------------------------------------
      | RL2   =RE-MCCURS                          |
      ---------------------------------------------
                     |
                     |
                 . * | * .
            . *     IF      * .
          *     RL3.GT.PHI       *
          * .                  . *--------------------------------------
            * .                . *       T     | RL2=RL2-PH2
                 * . *                          ------------------------
                     |                                       |
                     F                                       |
                     |----------------------------------------
                     |
                     |
                 . * | * .
            . *     IF      * .
          *     RL3.LT.-PHI      *
          * .                  . *--------------------------------------
            * .                . *       T     | RL3=PH2+RL2
                 * . *                          ------------------------
                     |                                       |
                     F                                       |
                     |----------------------------------------
                     |
```

STORE DETECTION DATA (STEP D21)

```
                     |
      ---------------------------------------------
      | JCONT=JCONT+1                             |
      | JMAX =MAX0(JMAX,JCONT)                    |
      | ICONT=JCONT                               |
      ---------------------------------------------
                     |
```

(CONTINUED ON PAGE 14)

```
                        |
                        |
                  . *   |  * .
             . *     IF       * .
           *    ICONT.GE.5        *
           * .                  . *-----------------------------------------
               * .    -     . *          T    | ICONT=5
                   *  .  *                    -----------------------------------------
                        |                             |
                        F                             |
                        |------------------------------
                        |


          STORE DATA IN ACCORDANCE WITH NUMBER SUCCESSIVE

          DETECTIONS (STEP D22)

 25            GO TO(30,31,32,33,34),ICONT
                        |
 30               . *   |  * .
             . *     IF       * .
           *  RMAX(1,1).NE.0.     *
           * .                  . *---------------------
               * .          . *          T    | 20    |
                   *  .  *                    ---------
                        |
                        F
                        |
                        |
                        |
            --------------------------------------------------
            | RMAX(1,1)  =DIST                               |
            | RMAX(1,2)  =(RELTC+DD)/RAD                     |
            --------------------------------------------------
                        |
                        |
                  . *   |  * .
             . *     IF       * .
           * RMAX(1,2).GT.180.    *
           * .                  . *-----------------------------------------
               * .          . *          T    | RMAX(1,2)=RMAX(1,2)-360.
                   *  .  *                    -----------------------------------------
                        |                             |
                        F                             |
                        |------------------------------
                        |
                        |
            --------------------------------------------------
            | RMAX(1,3)  =DMIN                               |
            | RMAX(1,4)  =RREL/RAD                           |
            | RMAX(1,5)  =RELA/RAD                           |
            | RMAX(1,6)  =ELE/RAD                            |
            --------------------------------------------------
                        |
                        |
                   ---------
                   | 20    |
                   ---------
```

(CONTINUED ON PAGE 15)

```
                 |
            . *  |  * .
       . *      IF      * .
     *  RMAX(2,1).NE.0.   *
     * .                . *-------------------
         * .         . *          T     | 20  |
            *   .   *                    ------
                |
                F
                |
                |
     ------------------------------------------
     | RMAX(2,1)  =DIST                        |
     | RMAX(2,2)  =(RELTO+DD)/RAD              |
     ------------------------------------------
                |
                |
            . *   * .
       . *      IF      * .
     * RMAX(2,2).GT.180.  *
     * .                . *-------------------------------
         * .         . *          T     | RMAX(2,2)=RMAX(2,2)-360.
            *   .   *                   -------------------------
                |                             |
                F                             |
                |------------------------------
                |
     ------------------------------------------
     | RMAX(2,3)  =DMIN                        |
     | RMAX(2,4)  =RREL/RAD                    |
     | RMAX(2,5)  =RELA/RAD                    |
     | RMAX(2,6)  =RLE/RAD                     |
     ------------------------------------------
                |
             -------
             | 20  |
             -------

                 |
32          . *  |  * .
       . *      IF      * .
     *  RMAX(3,1).NE.0.   *
     * .                . *-------------------
         * .         . *          T     | 20  |
            *   .   *                    ------
                |
                F
                |
                |
     ------------------------------------------
     | RMAX(3,1)  =DIST                        |
     | RMAX(3,2)  =(RELTO+DD)/RAD              |
     ------------------------------------------
                |
```

(CONTINUED ON PAGE 16)

```
                   |
                   |
             . *   |  * .
          . *     IF      * .
       *  BMAX(3,2).GT.180.  *
       * .                   . *-----------------------------------------------
          * .             . *          T     | BMAX(3,2)=BMAX(3,2)-360.
             * .       . *                   ----------------------------------
                   |                                 |
                   F                                 |
                   |---------------------------------
                   |
                   |
    -------------------------------------------------------------
    | BMAX(3,3)   =DMIN                                          |
    | BMAX(3,4)   =BREL/RAD                                      |
    | BMAX(3,5)   =RELA/RAD                                      |
    | BMAX(3,6)   =BLE/RAD                                       |
    -------------------------------------------------------------
                   |
                   |
               ---------
               | 20    |
               ---------


                   |
                   |
33           . *   |  * .
          . *     IF      * .
       *   BMAX(4,1).NE.0.   *
       * .                   . *-----------------------
          * .             . *          T     | 20    |
             * .       . *                   ---------
                   |
                   F
                   |
                   |
    -------------------------------------------------------------
    | BMAX(4,1)   =DIST                                          |
    | BMAX(4,2)   =(RELTO+DD)/RAD                                |
    -------------------------------------------------------------
                   |
                   |
                   |
             . *   |  * .
          . *     IF      * .
       *  BMAX(4,2).GT.180.  *
       * .                   . *-----------------------------------------------
          * .             . *          T     | BMAX(4,2)=BMAX(4,2)-360.
             * .       . *                   ----------------------------------
                   |                                 |
                   F                                 |
                   |---------------------------------
                   |
                   |
    -------------------------------------------------------------
    | BMAX(4,3)   =DMIN                                          |
    | BMAX(4,4)   =BREL/RAD                                      |
    | BMAX(4,5)   =RELA/RAD                                      |
    | BMAX(4,6)   =BLE/RAD                                       |
    -------------------------------------------------------------
                   |
```

(CONTINUED ON PAGE 17)

```
                  |
                  |
               -------
               | 20  |
               -------


                  |
                  |
 34             . * | * .
             . *   IF    * .
           *  RMAX(5,1).NE.0.  *
           * .                 . *-------------------
               * .         . *            T      | 20   |
                  * . *                          --------
                    |
                    F
                    |
                    |
           ------------------------------------------------
           | RMAX(5,1)  =DIST                             |
           | RMAX(5,2)  =(RELTO+DD)/RAD                   |
           ------------------------------------------------
                    |
                    |
                 . * | * .
              . *   IF    * .
           * RMAX(5,2).GT.180.  *
           * .                 . *----------------------------------
               * .         . *            T      | RMAX(5,2)=RMAX(5,2)-360.
                  * . *                          ------------------------
                    |                                    |
                    F                                    |
                    |-------------------------------------
                    |
                    |
           ------------------------------------------------
           | RMAX(5,3)  =DMIN                             |
           | RMAX(5,4)  =RREL/RAD                         |
           | RMAX(5,5)  =RELA/RAD                         |
           | RMAX(5,6)  =ELE/RAD                          |
           ------------------------------------------------
                    |
                    |
               -------
               | 20  |
               -------



        IF NO DETECTION, SET DETECTION STATUS


                    |
           ------------------------------------------------
 15        | ICONT=0                                      |
           | JCONT=0                                      |
           ------------------------------------------------
                    |
 20        RETURN

END
```

```
                        |
     A TORPEDO SIMULATION.   FUNCTION BEARIN.

         FUNCTION BEARIN(A,B,C,D)
     TO CALCULATE BEARING FROM TORPEDO TO TARGET
                        |
         ----------------------------------------
         | DIFX =A-C                            |
         | DIFY =B-D                            |
         | PH2  =2.*3.141592654                 |
         | RAD  =PH2/360.                       |
         ----------------------------------------
                        |
                        |
                  . *   |  * .
              . *      IF      * .
             *     DIFY.NE.0.      *
             * .                 . *--------------------
               * .             . *         T     | 16  |
                   *    .   *                    -------
                        |
                        F
                        |
                        |
         ----------------------------------------
         | BB   =90.*RAD                        |
         ----------------------------------------
                        |
                        |
                  . *   |  * .
              . *      IF      * .
             *     DIFX.LT.0.      *
             * .                 . *----------------------------------
               * .             . *         T     | BB=BB+(180.*RAD)
                   *    .   *                    ------------------------
                        |                              |
                        F------------------------------
                        |
                        |
                     -------
                     | 17  |
                     -------

                        |
  16     ----------------------------------------
         | BB   =ATAN2(DIFX,DIFY)               |
         ----------------------------------------
                        |
```

(CONTINUED ON PAGE 2)

```
                        |
                        |
                 .  *   |  *  .
             .  *      IF       *  .
          *           RB.LT.0.         *
          *  .                      .  *--------------------------------------
               *  .             .  *          T     | RB=RB+PI2
                     *  .  *                        --------------------------
                        |                                  |
                        F                                  |
                        |-----------------------------------
                        |
                        |
              ------------------------------------------------
   17         | BEARIN =RB                                   |
              ------------------------------------------------
                        |

              RETURN

END
```

```
                 |
    A TORPEDO SIMULATICN.   FUNCTION XFACT.

        FUNCTION XFACT(X,Y)
    CALCULATE REDUCTICN-FACTOR IN TRANSDUCER GAIN DUE

    TO RELATIVE BEARING OFF CENTER-HEADING CF TORPEDC

        DOUBLE PRECISICN X,XFACT,XY,Y
                 |
        ------------------------------------------
        | PHI  =3.141592654                      |
        ------------------------------------------
                 |
                 |
                 |
            . *     * .
         . *    IF      * .
        *     X.EQ.0.      *
        * .              . *-------------------------
           * .        . *           T     | 10   |
              * .  . *                    --------
                 |
                 F
                 |
                 |
                 |
        ------------------------------------------
        | XY    =X/Y                             |
        | XFACT=DABS((DCOS(X*0.5)*DSIN(XY        |
        |       *PHI))/(XY*PHI))                 |
        ------------------------------------------
                 |
        RETURN
                 |
        ------------------------------------------
10      | XFACT=1.                               |
        ------------------------------------------
                 |
        RETURN

END
```

```
                   |
   A TORPEDO SIMULATION.   FUNCTION SCALE.

        FUNCTION SCALE(Y)
   CALCULATE SCALING FACTOR IN THE PROCESS OF

   COMPUTING TARGET STRENGTH

        DOUBLE PRECISION SCALE,RELB,Z,Y


                   |
      ----------------------------------------
      | PHI   =3.151592654                   |
      ----------------------------------------
                   |
                   |
                   |
               . *   * .
           . *    IF     * .
         *    Y.GT.PHI/2.    *
         * .                 . *--------------------------------------
             * .         . *          T       | Y=PHI-Y
                 *  .  *                      -------------------------
                   |                               |
                   F                               |
                   |--------------------------------
                   |
                   |
      ----------------------------------------
      | Z      =0.251635*(Y**2)-0.18555*Y     |
      | Z      =Z+0.0365*DSIN(3.*(Y+0.17453)) |
      |          +0.015*(Y**2)*DSIN(9.*Y/2.)  |
      | SCALE=1./Z                            |
      ----------------------------------------
                   |

        RETURN

END
```

APPENDIX C

DETAILED RUN PRINTOUT

```
TACTICAL SITUATION WHEN FIRING
FIRING RANGE    ATTACK ANGLE    TARGET COURSE   TARGET SPEED
  3000.0            -60.0            270.0            20.0

TORPEDO PARAMETERS
TECH.DET.RANGE  TRANS.INT.VAL   TORP SPEED    SWEEP ANGLE
   750.00            1.00           40.0          30.0

LOBE WIDTH        TURN RATE
   20.0              0.0
THEORETICAL WIDTH OF TACTICAL SWEEP-LANE   1149.1
THEORETICAL COVERAGE RATIO    0.8500

SONAR MAIN LOBE OFF-SET FROM CENTER BEARING  0.0  TIMES DEFLECTION ANGLE


      RUN NUMBER     :    1
EST OF TARGET DATA FOR FIRING
   COURSE      SPEED        RANGE
   256.5        12.4      3345.1
TORP DEFLECTION ANGLE IS    -12.07
TORPEDO MAIN COURSE           17.03
RUN STOPPED AFTER    136 SECONDS

RUN DATA AS FOLLOWS AT END OF RUN
TOTAL TORP RUN      2730.0
DIST TO TARGET       513.0
TORP X-COORD       14274.5     TORP Y-COORD      14889.0
TARGET X-COORD     13771.5     TARGET Y-COORD    15000.0
TORP MAIN COURSE     17.027          TORP COURSE     357.025
NO DETECTION MADE DURING THIS RUN

      RUN NUMBER     :    2
EST OF TARGET DATA FOR FIRING
   COURSE      SPEED        RANGE
   256.5        14.2      2702.4
TORP DEFLECTION ANGLE IS    -14.87
TORPEDO MAIN COURSE           15.13
RUN STOPPED AFTER    147 SECONDS

RUN DATA AS FOLLOWS AT END OF RUN
TOTAL TORP RUN      2940.0
DIST TO TARGET       581.1
TORP X-COORD       14259.7     TORP Y-COORD      15000.0
TARGET X-COORD     13677.0     TARGET Y-COORD    15000.0
TORP MAIN COURSE     15.120          TORP COURSE      11.500

MAXIMUM DETECTION RANGES AND BEARINGS
SUCCESSIVE    MAX  DET           DET BEARING      MAX  DET              DET BEARING     TARGET
DET    NO.    RANGE - CENTER     CENTER           RANGE - CLOSEST       CLOSEST         ASPECT
     1            502.5            5.17              550.5                10.20         -27.58
     2            543.8           -1.40              530.5                 3.08         -30.30
     3              0.0            0.0                 0.0                 0.0            0.0
     4              0.0            0.0                 0.0                 0.0            0.0
     5              0.0            0.0                 0.0                 0.0            0.0
```

LIST OF REFERENCES

1. Barton,D.K., Radar system analysis, Prentice-Hall, 1964,
2. Camp,L., Underwater Acoustics, Wiley-Interscience, 1970,
3. Cox, A.C., Sonar And Underwater Sound, Lexington Books, 1974,
4. Edit. Crispin jr, J.W. and Siegel, K.M., Methods of Radar Cross-Section Analysis, Academic Press, 1968,
5. Edit. Stephens, R.W.B., Underwater Acoustic, Wiley-Interscience, 1970,
6. Urick, R.J, Principle Of Underwater Sound, McGraw-Hill, 1975,
7. Hutchings,P.J., The Mk. 24 Tigerfish Torpedo, International Defence Review, Vol 10, pg. 294-295, no 2, 1977,
8. International Defence Review, Some Modern Torpedo Developement, Vol 9, pg. 91-95, no 1, 1976,
9. Ramsauer, U., Torpedo Developement in Germany, International Defence Review, Vol 9, pg. 96-100, no 1, 1976,
10. Missile and Rockets, Torpedo Terms and Terminology, Vol 2, pg. 127-132, May 1957,
11. Ruhe, W.J., Capt., The Nuclear Submarine: Riding High, U S Naval Institute Proceedings, Vol 101, no 2, pg. 55-62, February 1975,

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defence Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Royal Norwegian Naval Headquarter Oslo Mil Oslo 1, Norway	2
3.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
4.	Department Chairman Department of Operations Research Naval Postgraduate School Monterey, California 93940	1
5.	Professor Alan R. Washburn Department of Operations Research Naval Postgraduate School Monterey, California 93940	1
6.	Professor Harold A. Titus Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	1
7.	Lt.Cdr. Anders Mjelde Oslo Mil Oslo 1, Norway	1

172683

Thesis
M6545
c.1

Mjelde

A homing torpedo the effect of the tactical situation and the torpedo parameters on the torpedo effectiveness.